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ARMSTRONG LABORATORY

HUMAN INTEGRATION EVALUATION OF THREE HELMET SYSTEMS (U)

Sherri Upchurch Blackwell

ANTHROPOLOGY RESEARCH PROJECT, INC.
503 XENIA AVENUE
YELLOW SPRINGS, OHIO 45387

Kathleen M. Robinette

CREW SYSTEMS DIRECTORATE
HUMAN ENGINEERING DIVISION
WRIGHT-PATTERSON AIR FORCE BASE OHIO 45433-7022

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INTERIM REPORT FOR PERIOD SEPTEMBER 1990 TO NOVEMBER 1992

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AL-TR-1993-0028

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Kenneth R. Boff

KENNETH R. BOFF, Chief
Human Engineering Division
Armstrong Laboratory

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Sherri Upchurch Blackwell
Kathleen M. Robinette

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503 Xenia Ave
Yellow Springs OH 454387

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As protective equipment becomes more complex, more sophisticated tests of fit and function must be designed to determine and assess the effects of interactions between the user and various elements of the equipment. Among the newest protective ensembles available on the market are helmets with built-in Night Vision Goggles (NVGs) or Helmet Mounted Displays (HMDs). A program called the Interim-Night Integrated Goggle and Head Tracking System (I-NIGHTS) was established to examine such helmets. Under this program, a series of fit and performance tests of three helmets systems was done. This report documents the fit, or human integration, evaluation designed to determine how well each helmet accommodated test subjects for comfort, stability, and optical placement. The test method used was the first to examine these three elements simultaneously as well as the first to include the measurement of head contour and three-dimensional placement of key human features. Results were intended to be used to better understand the fit related effects on later performance testing of subjects in a centrifuge, on a drop tower, and under actual flying conditions. Recommendations were made regarding design features which appear to be most effective for accommodating people.

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PREFACE

This study was carried out under contract F33615-89-C-0572 with Armstrong Laboratory, Wright-Patterson Air Force Base, Ohio. Funding and test support for the effort was provided by the Helmet Mounted Systems Technology Program Office. Program managers were Captain Karen Cooper and Mr. P. Scott Hall.

Mr. James Stiffler of Ball Systems Engineering Division provided invaluable assistance in coordinating the various tests, and lent his expertise to the fitting of the helmet liners. The authors are also grateful to Mr. Ronald Yates from the Human Engineering Division of Armstrong Laboratory who ably assisted in the fitting of the helmets and the liners, to Ms. Jennifer Whitestone from the Human Engineering Division of Armstrong Laboratory, for her assistance in the planning and execution of the 3-D helmet scanning, and to Captain John Crist from the Human Engineering Division of Armstrong Laboratory, for his assistance in reviewing the text. The optic assessments were considerably facilitated by Ms. Mary Perry of the Human Engineering Division of Armstrong Laboratory, and Mr. Joseph Riegler of Logicon Technical Services, Inc. Ms. Mary Gross of Beecher Research Company and Ms. Joyce Robinson of Systems Research Laboratory assisted with the statistics.

Thanks go also to Ms. Ilse Tebbetts of Anthropology Research Project who served as technical editor, and to Ms. Jennifer Schinhofen, who assisted in the production of this report.

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INTRODUCTION

As personal protective equipment becomes more complex, more sophisticated tests of fit and function must be designed to determine and assess the effects of interactions between the user and various elements of the equipment. Among the newest protective ensembles available on the market are helmets with built-in Night Vision Goggles (NVGs) or Helmet Mounted Displays (HMDs). A program called the Interim-Night Integrated Goggle and Head Tracking System (I-NIGHTS) was established to examine such helmets. Under this program, the Helmet Mounted Systems Technology (HMST) Program Office undertook a series of fit and performance tests of three candidate systems manufactured by GEC Avionics, Kaiser Electronics, and Honeywell, Inc. This report documents the fit, or human integration, evaluation designed to determine how well each helmet accommodated test subjects for comfort, stability, and optical placement.

The test method was the first to examine these three elements simultaneously in order to assess the effects of each upon the others. Results were intended to be used to better understand the fit-related effects on later performance testing of subjects in a centrifuge, on a drop tower, and under actual flying conditions. It should be noted that the fit results were not used to eliminate subjects from any of the performance tests; subjects were used to assess helmet performance regardless of whether the helmet fit or not.

The test design was also the first to incorporate the quantification of head *shape* (in addition to head size), and three-dimensional spatial locations of key human features into the data collection. This information will enable designers of helmet systems, in the future, to evaluate the effect of head shape on fit. Further research into these effects is planned.

METHODS

SUBJECTS

The subjects were selected by other test organizations, not necessarily as a representative sample of the USAF user population. The purpose of this test was to provide information on the fit of the helmets for fixed individuals so that the effect of fit on performance during other testing could be examined, and separated from design effects.

A total of 37 test subjects participated in the fit assessment. Those subjects can be grouped as follows:

- Twelve test subjects (two rated and ten non-rated) from the Combined Stress Branch of the Biodynamics/Bioengineering Division, scheduled for performance testing in the centrifuge.

- Twelve non-rated test subjects from the Escape and Impact Protection Branch, formerly the Crew Protection Branch of the Biodynamics/ Bioengineering Division, scheduled for performance testing on the drop tower.

- Thirteen pilots from Ellsworth AFB, SD, Moffett Field, CA, and Hurlburt Field, FL scheduled for in-flight performance testing.

Bivariate plots (Head Length by Head Breadth) comparing the I-NIGHTS males to existing male data are presented in Figures 1-4. Demographic information on all subjects is presented in Table 1. Existing male data are from the 1964 Survey of Navy Aviators (Gifford et al., 1965), the 1967 Survey of Air Force Pilots (Kennedy, 1986), the 1988 Survey of Army Personnel (Gordon et al., 1989), and the 1990 Survey of Air Force Flyers (Blackwell et al., in press). These figures indicate that the subjects were distributed throughout the range for these variables.

HELMETS

Configurations

Each vendor provided two helmet configurations: the Night Vision Goggles (NVGs) and the Helmet Mounted Displays (HMDs). Cathode Ray Tubes (CRTs) distinguish the NVG from the HMD. Both configurations (NVG and HMD) use two image intensifier tubes to amplify ambient moon and star light. The HMD, however, also features two miniature CRTs which enable the HMD to display mission-critical information that is always visible to a crew member regardless of the direction he or she may be looking.

The HMD helmets are slightly heavier than the NVG helmets and the effect of the extra weight on stability and comfort was taken into consideration during testing.

The bulk of the fit assessment is composed of NVG data.

Operational and Mock-Up Helmets

The I-NIGHTS vendors created operational and non-operational (or mock-up) versions of both the NVG and HMD helmets. Differences in the performance testing dictated which subjects would be tested in which version of a helmet. The centrifuge test subjects and the 13 pilots required operational optics for their performance tests. The drop tower test subjects were tested in the mock-ups of the NVG helmets because drop tower testing examined the performance of the I-NIGHTS helmets during simulated seat ejections and did not require the use of the optical system.

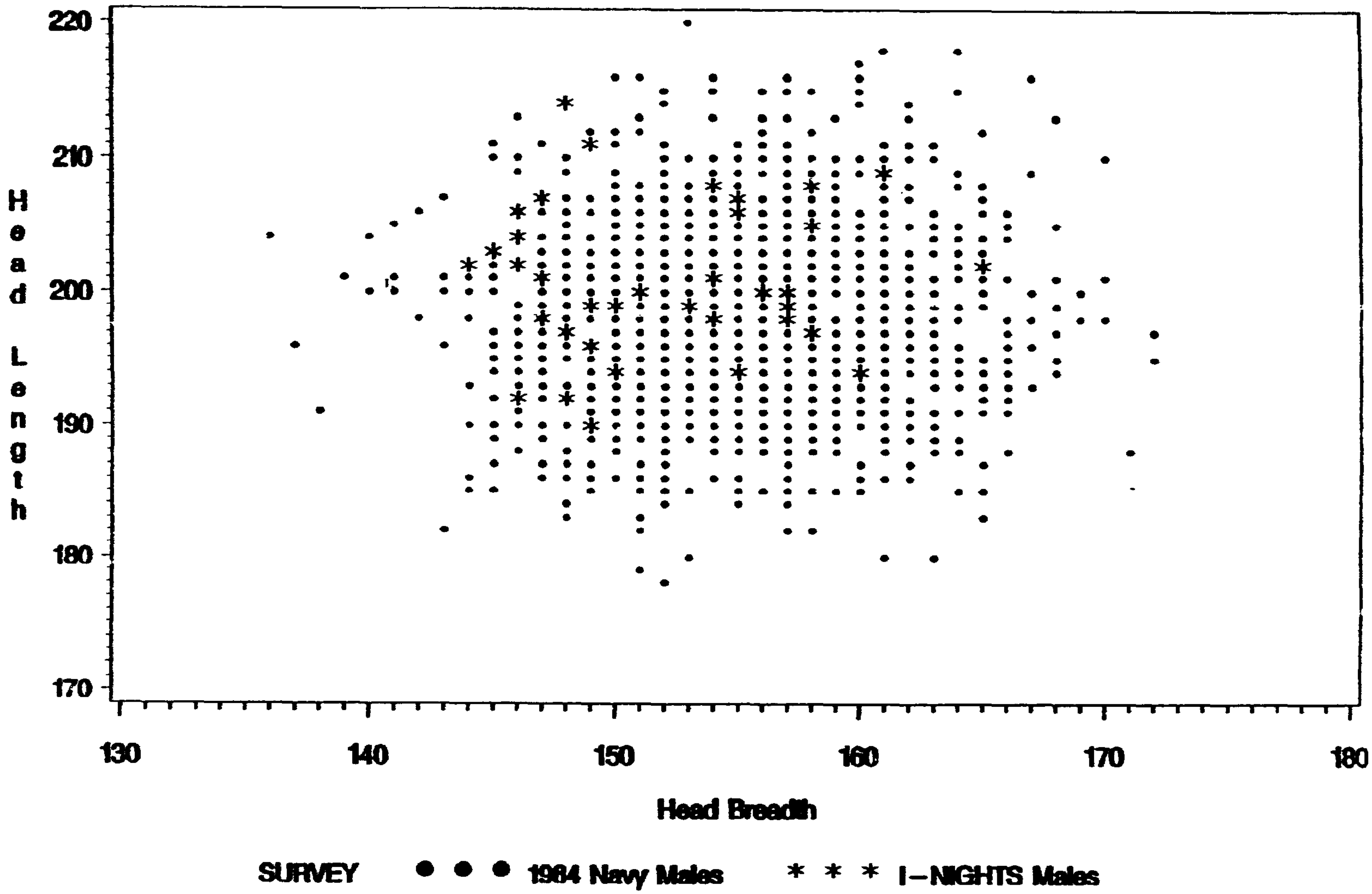


FIGURE 1

A Bivariate Plot for 1964 Navy Males and I-NIGHTS Males
(values in mm)

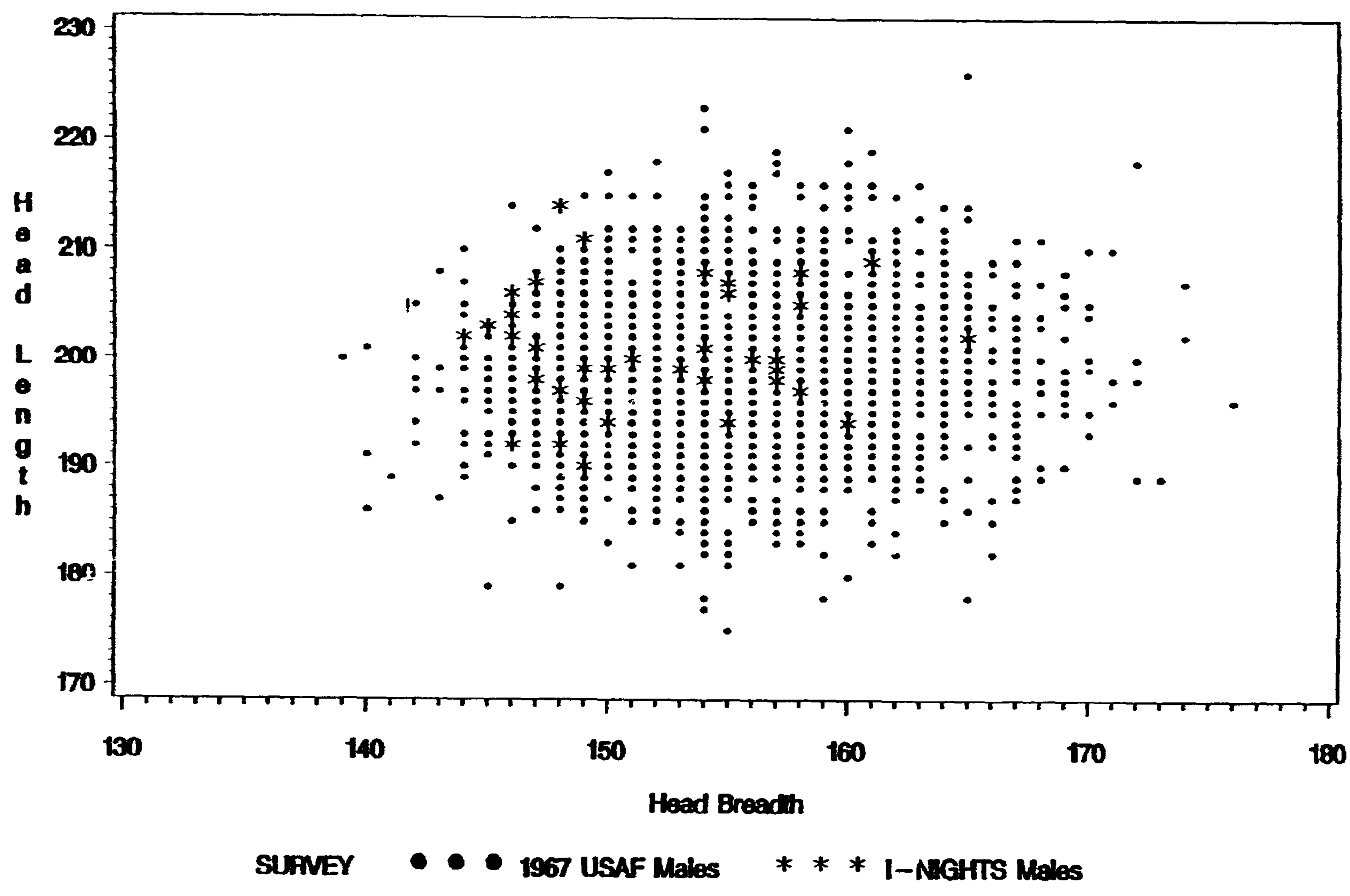


FIGURE 2

A Bivariate Plot for 1967 Air Force Males and I-NIGHTS Males
(values in mm)

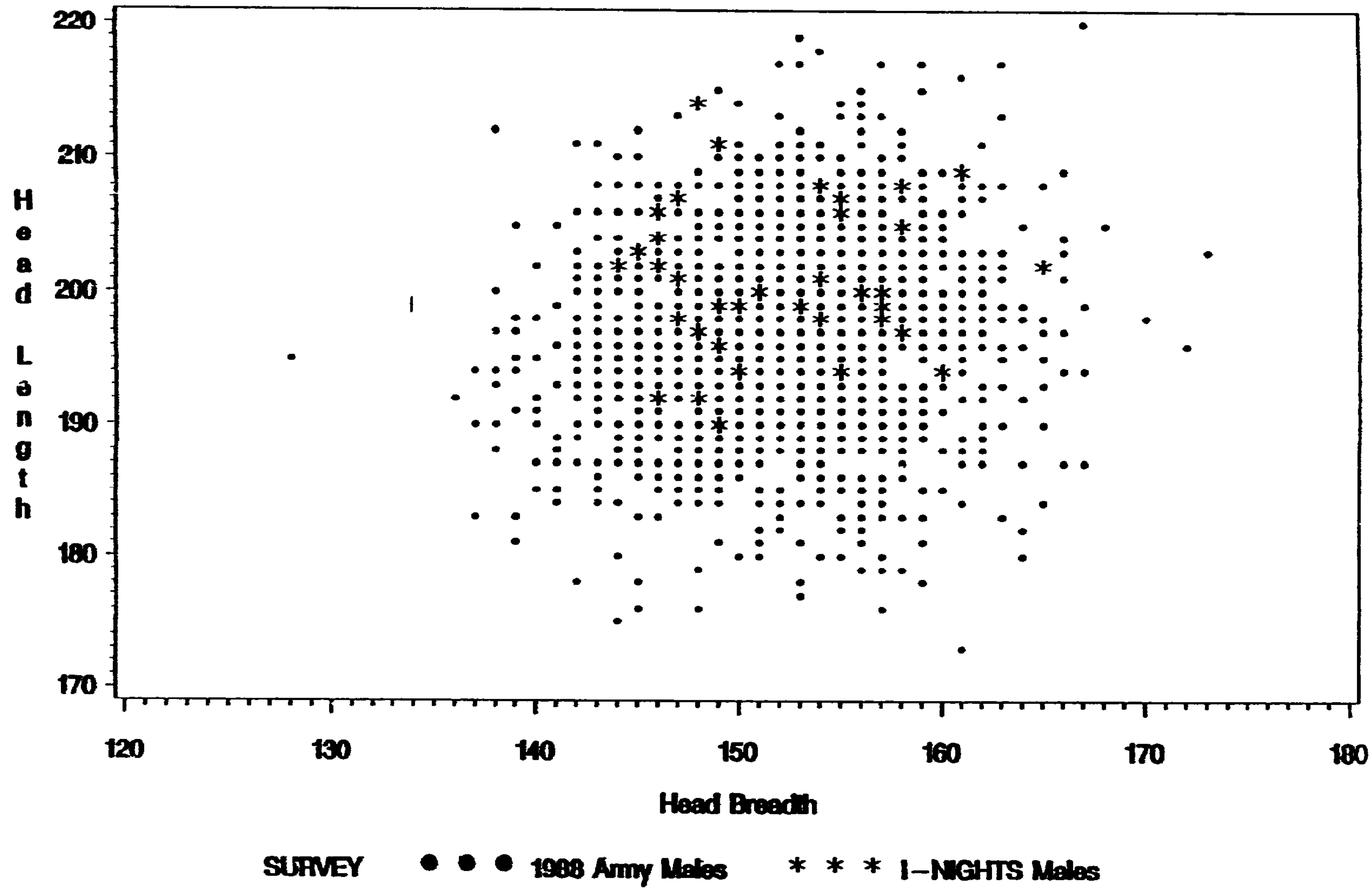


FIGURE 3

A Bivariate Plot for 1988 Army Males and I-NIGHTS Males
(values in mm)

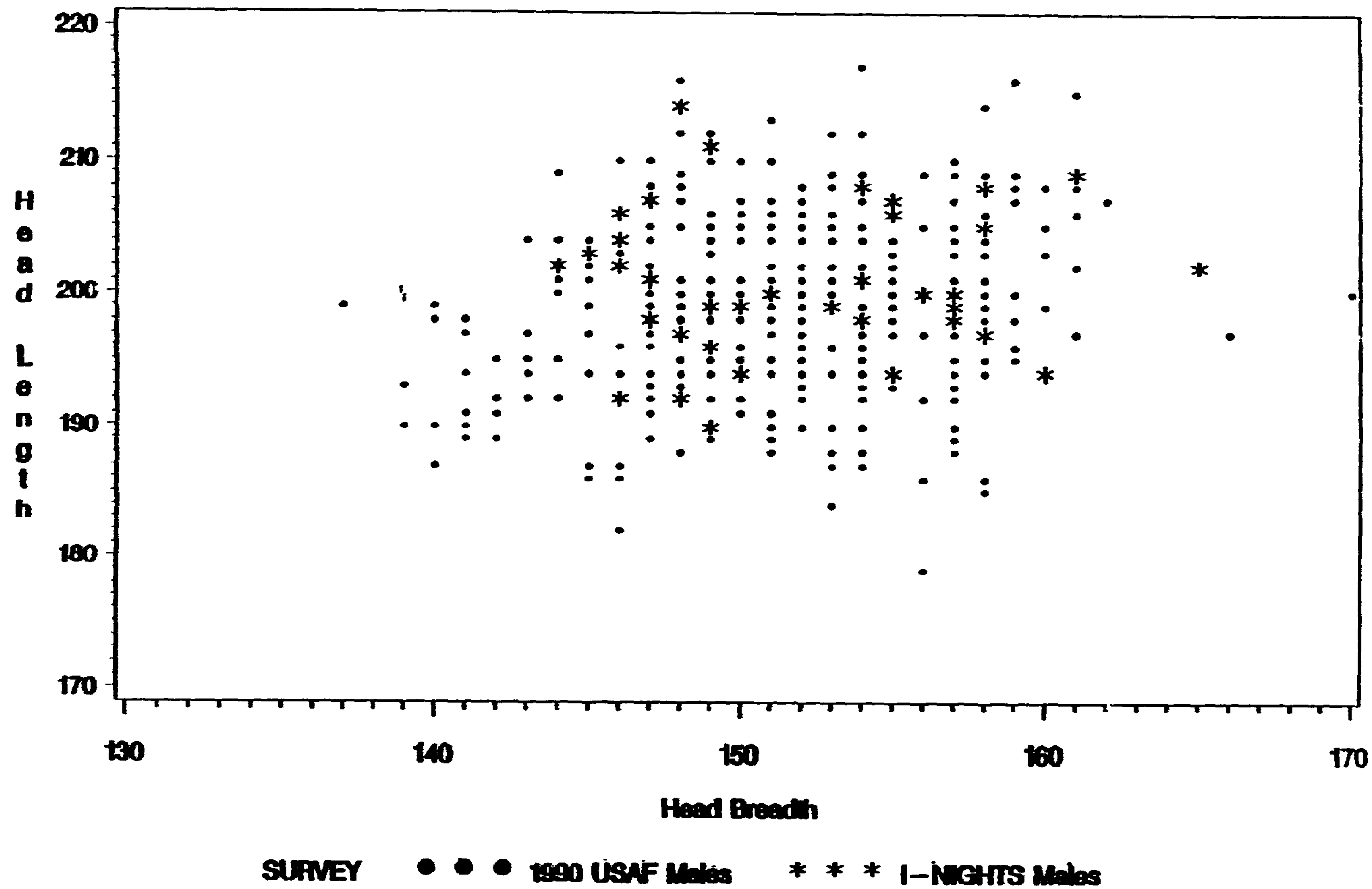


FIGURE 4

A Bivariate Plot for 1990 Air Force Males and I-NIGHTS Males
(values in mm)

TABLE 1

Demographic Variables: I-NIGHTS Males

SEX	FREQUENCY	PERCENT	CUMULATIVE FREQUENCY	CUMULATIVE PERCENT
F	2	5.4	2	5.3
M	35	94.6	37	100.0

AGE	FREQUENCY	PERCENT	CUMULATIVE FREQUENCY	CUMULATIVE PERCENT
24	5	13.5	5	13.5
25	2	5.4	7	18.9
26	5	13.5	12	32.4
27	1	2.7	13	35.1
28	1	2.7	14	37.8
29	8	21.6	22	59.4
31	3	8.1	25	67.5
32	1	2.7	26	70.2
33	1	2.7	27	72.9
34	2	5.4	29	78.3
35	1	2.7	30	81.0
36	1	2.7	31	83.7
38	1	2.7	32	86.4
39	1	2.7	33	89.1
40	1	2.7	34	91.8
41	2	5.4	36	97.2
42	1	2.7	37	99.9

TABLE 1 (cont'd)

RACE	FREQUENCY	PERCENT	CUMULATIVE FREQUENCY	CUMULATIVE PERCENT
Black	1	2.7	1	2.6
Hispanic	1	2.7	2	5.3
White	35	94.6	37	100.0

"Best" Helmet Location

Although a trained investigator visually assessed the placement of a helmet on a subject's head, the helmet could not be considered to be at the "best" location (with respect to the optics) unless an image viewed through the activated optical system met the criteria discussed on page 19 (Optical Placement Assessment).

Because the mock-ups lacked functioning optical systems, placement of these helmets could be determined through visual assessment only. Therefore, placement of the mock-up helmets was "best guess" on the part of the investigator rather than a precise location achieved with reference to an operating optical system.

The evaluation of all helmets consisted of the following steps:

- helmet liner preparation
- the gathering of traditional and three-dimensional (3-D) anthropometric data
- I-NIGHTS helmet fit assessments

HELMET LINER PREPARATION

Prior to the actual fit assessment, each subject reported to three helmet liner preparation sessions, each conducted by one of the three I-NIGHTS helmet vendors or by qualified personnel at the Armstrong Laboratory. The vendor's finished product was a helmet liner which was worn within the shell of the I-NIGHTS helmet to cushion the top of the subject's head from the hard interior surfaces of the helmet shell itself, to help align the helmet, and to provide stability and comfort. The liners were molded to the subjects' heads.

For the Kaiser and Honeywell systems, it was determined by the vendors after some preliminary testing, that the liners should be made for the specific helmet to be used. The performance of the helmets suffered when a liner fashioned to fit one was worn in another. The liners were formed while the subject held the helmet in the "best" location for the helmet tests. This may have given these two types an optical advantage over the GEC helmet. The GEC liner required the use of a liner fitting tool. This was a sort of mold rather than an actual helmet, resulting in a fit which was customized to the subject's head but not to individual helmets.

The customized liners are referred to as "comfort" liners. There was also a liner in each helmet for energy absorption, referred to as an "energy" liner. An important difference between the Kaiser and Honeywell liners is that Honeywell uses a one-piece liner and Kaiser does not. In the Kaiser system the energy liner within the shell of the helmet varies slightly from helmet to helmet. It is composed of several moldings which are taken from the shell of the helmet and fused. Due to the slight variations between the helmets and the fact that the energy liner is not one large piece, Kaiser asserts that the liners are not interchangeable (between helmets). Because it is necessary for each person using an operational system to have both a primary and a back-up system available for performance testing, each person using an operational Kaiser helmet must be fit in both a primary and back-up system. The Kaiser NVG was assessed as the primary system and the Kaiser HMD was assessed as the back-up system.

THE ANTHROPOMETRY

Anthropometric measurements were made to determine the representativeness of the test sample with respect to user populations. The anthropometric measurement session consisted of six head measurements with the head bare, six head measurements with the head covered with a bald-cap (simulating baldness and providing cranial data unobscured by hair), eight face measurements, two ear measurements, three eye (pupil) measurements, and a series of 3-D surface scans of the head and face. Summary statistics of the I-NIGHTS male test subject anthropometry are presented in Table 2.

Prior to measuring subjects, a trained investigator located the anatomical landmarks which serve as the origin or termination points of some measurements and as the midpoints of other measurements. The landmarks were located and drawn lightly on the skin with a cosmetic pencil. They are illustrated in Figures 5 and 6.

Once the anatomical landmarks were identified and the manual measurements had been taken, adhesive-backed felt dots were placed over the pencil marks to ensure that all landmarks would be visible on the 3-D images.

An unencumbered 3-D scan was taken with the "bald" subject positioned in the Frankfort Plane (the standard orientation of the head which is established by a horizontal line passing through the right tragion and the right bony eye socket). A second unencumbered scan was taken with the head tilted back and the subject looking up toward the ceiling. This position altered the orientation of the chin and allowed for the collection of data on the lower face and in the mandibular region which was obscured by shadowing or by the chin itself when the head was scanned in the standard position.

For the test pilots, several additional 3-D scans were also taken. The purpose of these scans, referred to as the "helmet" scans, was to establish the spatial relationship between the I-NIGHTS helmets and the subjects' heads. These additional scans will allow future workers to define the mass properties of the helmet for each individual. Additionally, the optics can be defined with respect to pupil location.

All I-NIGHTS 3-D scan data have been stored in a data base for future use. A plot of a test subject's unencumbered 3-D head scan data is shown in Figure 7. A plot of 3-D helmet scan data is shown in Figure 8.

TABLE 2

Anthropometry of I-NIGHTS Subjects: Summary Statistics - Males (mm)

Dimension	N	Mean	SD	Skewness	Kurtosis	Minimum	Median	Maximum
Age (years)	35	30.6	5.5	0.7	-0.6	24.0	29.0	42.0
Bigonial Breadth	35	111.1	6.9	0.4	0.7	98.0	111.0	131.0
Bitragion-Coronal Arc	2	349.0	24.0	---	---	332.0	349.0	366.0
Bitragion-Coronal Arc (Cap)	34	365.4	11.1	-0.2	-0.3	340.0	365.0	385.0
Bitragion Menton Arc	35	327.7	13.0	0.7	1.2	304.0	330.0	368.0
Bitragion-Minimum Frontal Arc	35	300.5	10.0	0.3	0.6	280.0	300.0	327.0
Bitragion-Submandibular Arc	35	310.3	14.9	0.2	-0.1	275.0	308.0	341.0
Bitragion-Subnasale Arc	35	284.5	10.6	1.0	2.5	264.0	282.0	316.0
Bizygomatic Breadth	35	143.0	5.0	0.6	0.0	135.0	142.0	156.0
Ear Breadth	35	34.9	3.1	0.0	-0.9	30.0	35.0	41.0
Ear Length	35	65.1	3.9	0.0	-1.1	58.0	65.0	72.0
Head Breadth	35	152.2	5.3	0.4	-0.7	144.0	151.0	165.0
Head Breadth (Cap)	33	155.8	5.2	0.0	-0.8	147.0	156.0	166.0
Head Circumference	35	578.8	12.6	0.1	-0.8	558.0	578.0	604.0
Head Circumference (Cap)	33	583.8	11.8	-0.1	-0.8	562.0	583.0	605.0
Head Length	35	201.1	5.5	0.2	-0.2	190.0	200.0	214.0
Head Length (Cap)	33	204.8	5.1	0.0	0.1	193.0	204.0	216.0
Interpupillary Distance	34	64.4	2.9	-0.3	-0.7	58.0	64.5	69.0
Interpupillary Distance - Rt	30	32.4	1.7	-0.6	0.4	28.5	32.5	36.0
Interpupillary Distance - Lt	30	32.3	1.7	-0.5	-0.1	28.0	32.5	35.0
Menton-Nasal Root Depression	35	124.3	6.9	-0.1	-1.0	112.0	125.0	136.0
Nose Breadth	35	35.1	3.4	0.4	-0.2	29.0	35.0	43.0
Pupil-Top of Head	35	110.0	10.5	0.0	-0.9	91.0	111.0	130.0
Pupil-Top of Head (Cap)	33	120.9	9.3	-0.1	-1.1	104.0	122.0	136.0
Tragion-Top of Head	35	127.5	7.2	-0.4	-1.0	111.0	129.0	137.0
Tragion-Top of Head (Cap)	33	132.2	6.1	-0.4	-0.8	121.0	133.0	143.0

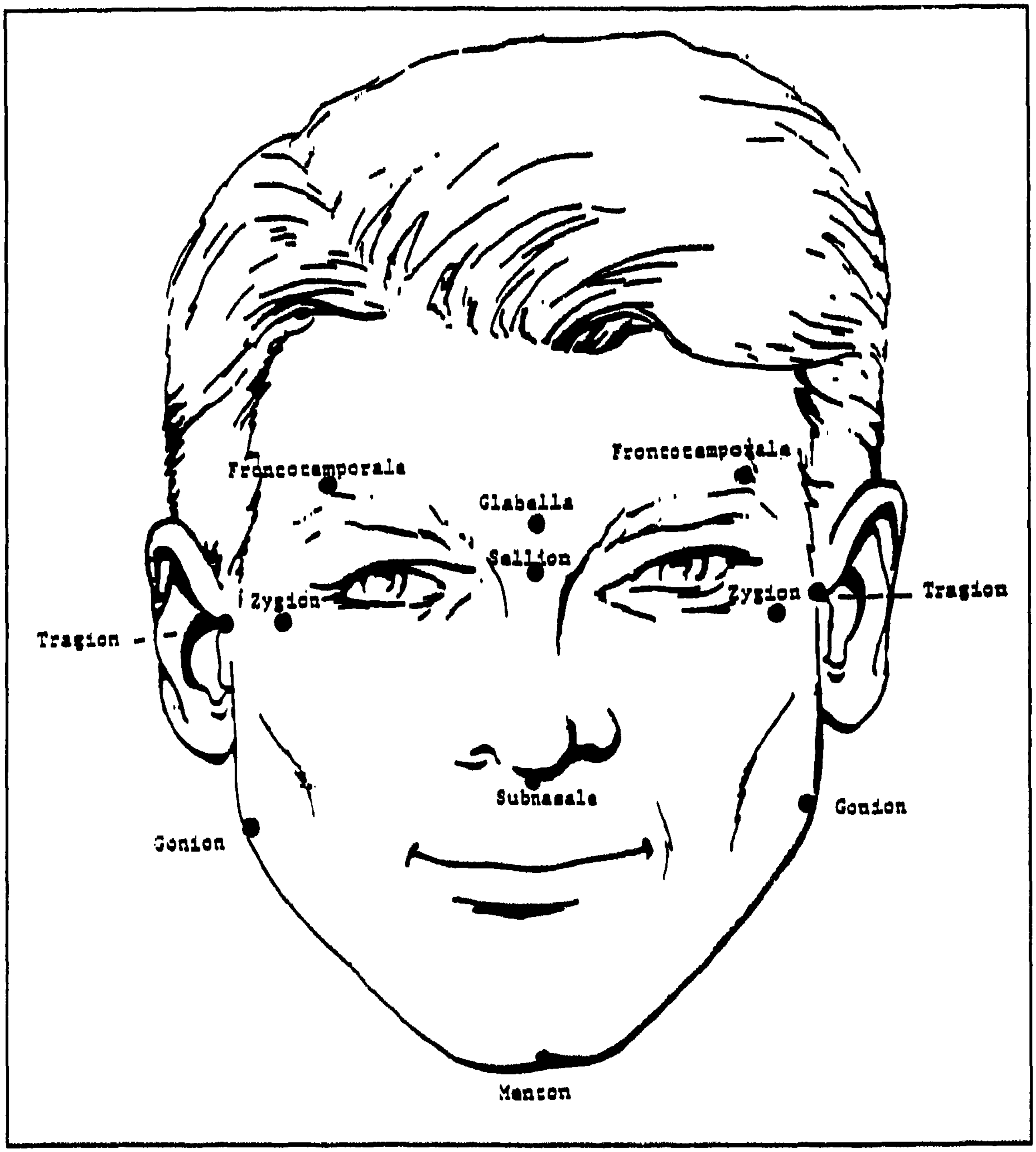


FIGURE 5

The Marked Anthropometric Landmarks

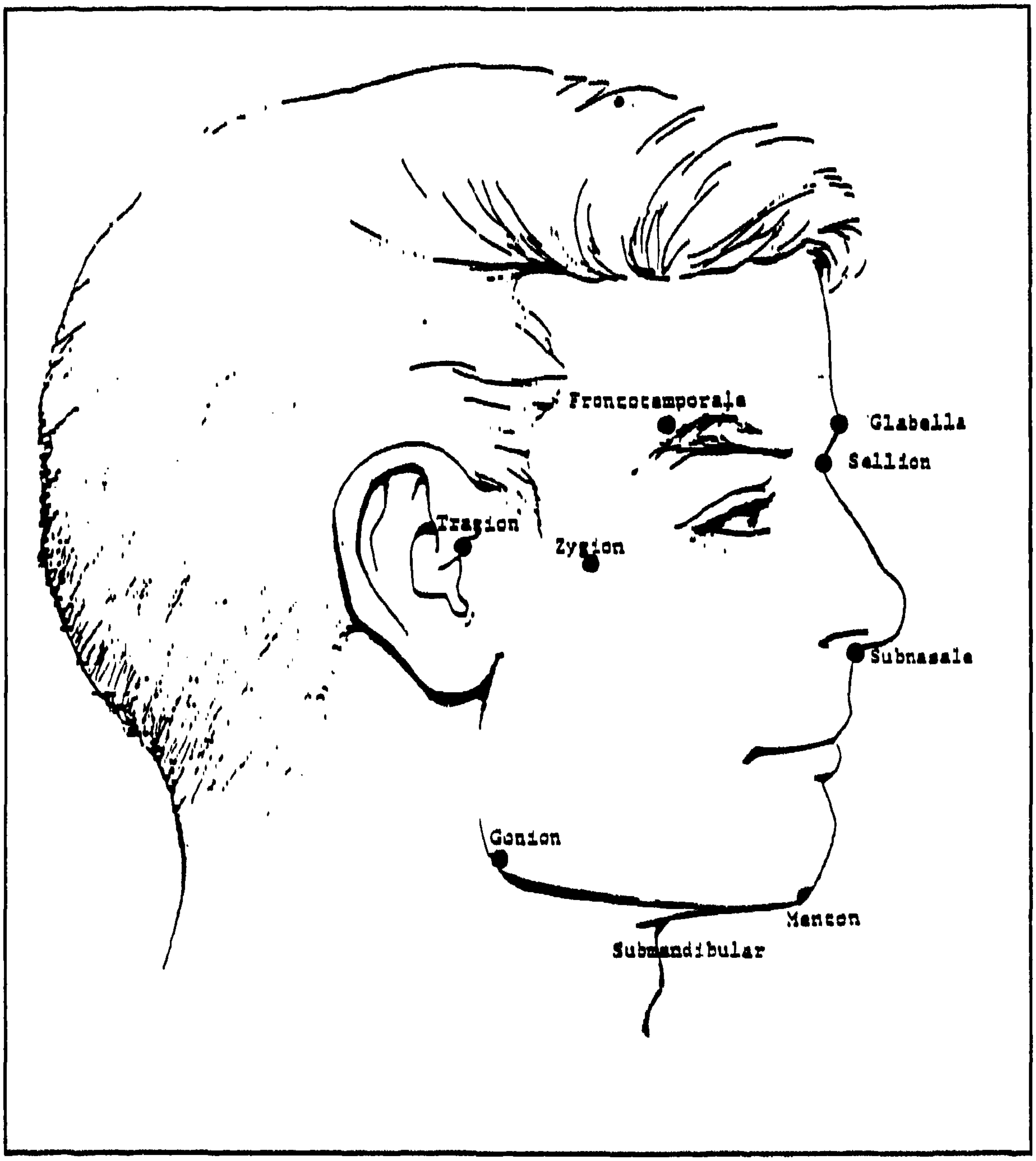


FIGURE 6

A Side View of the Marked Anthropometric Landmarks

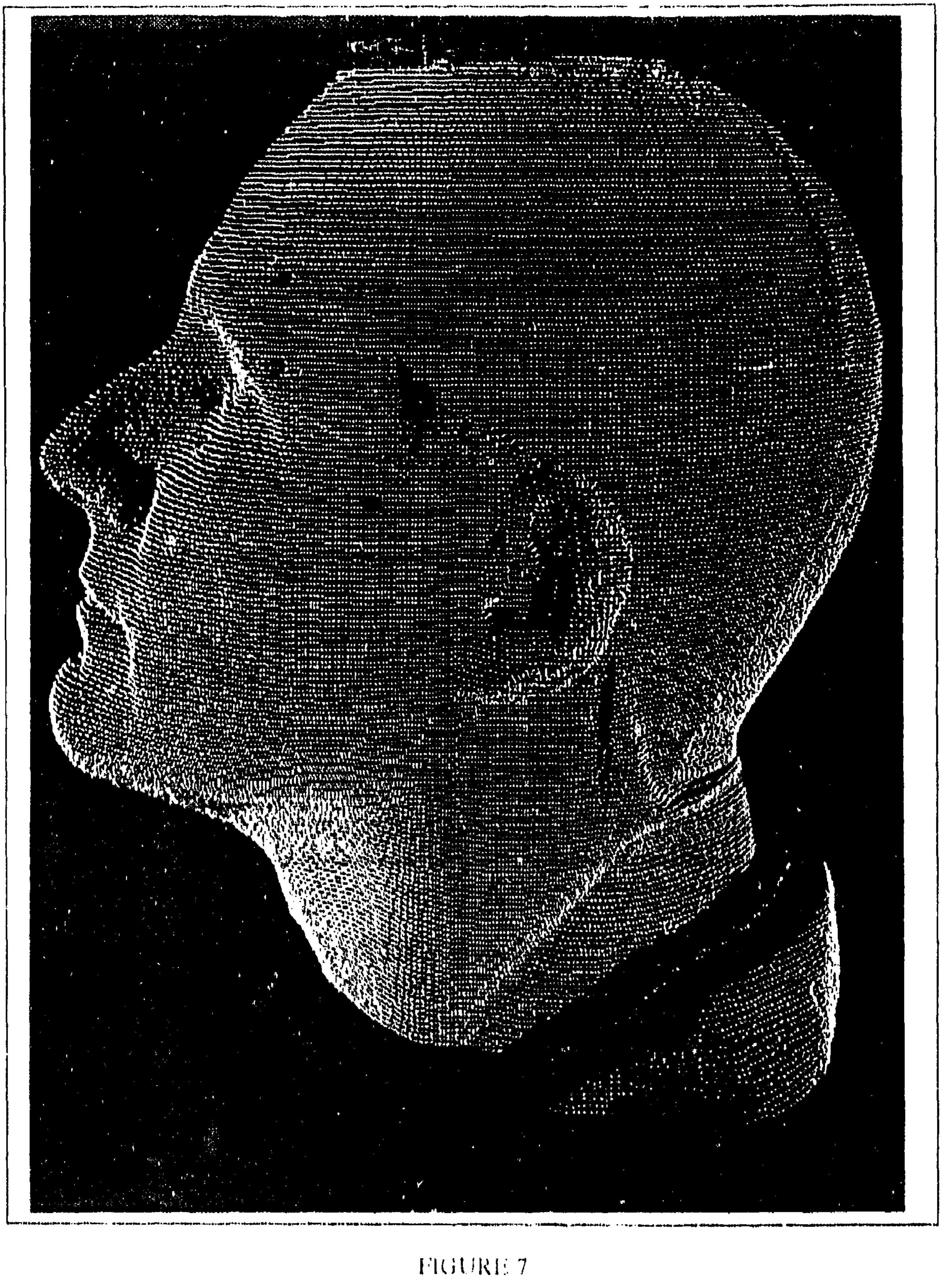


FIGURE 7

3-D Head Scan Data

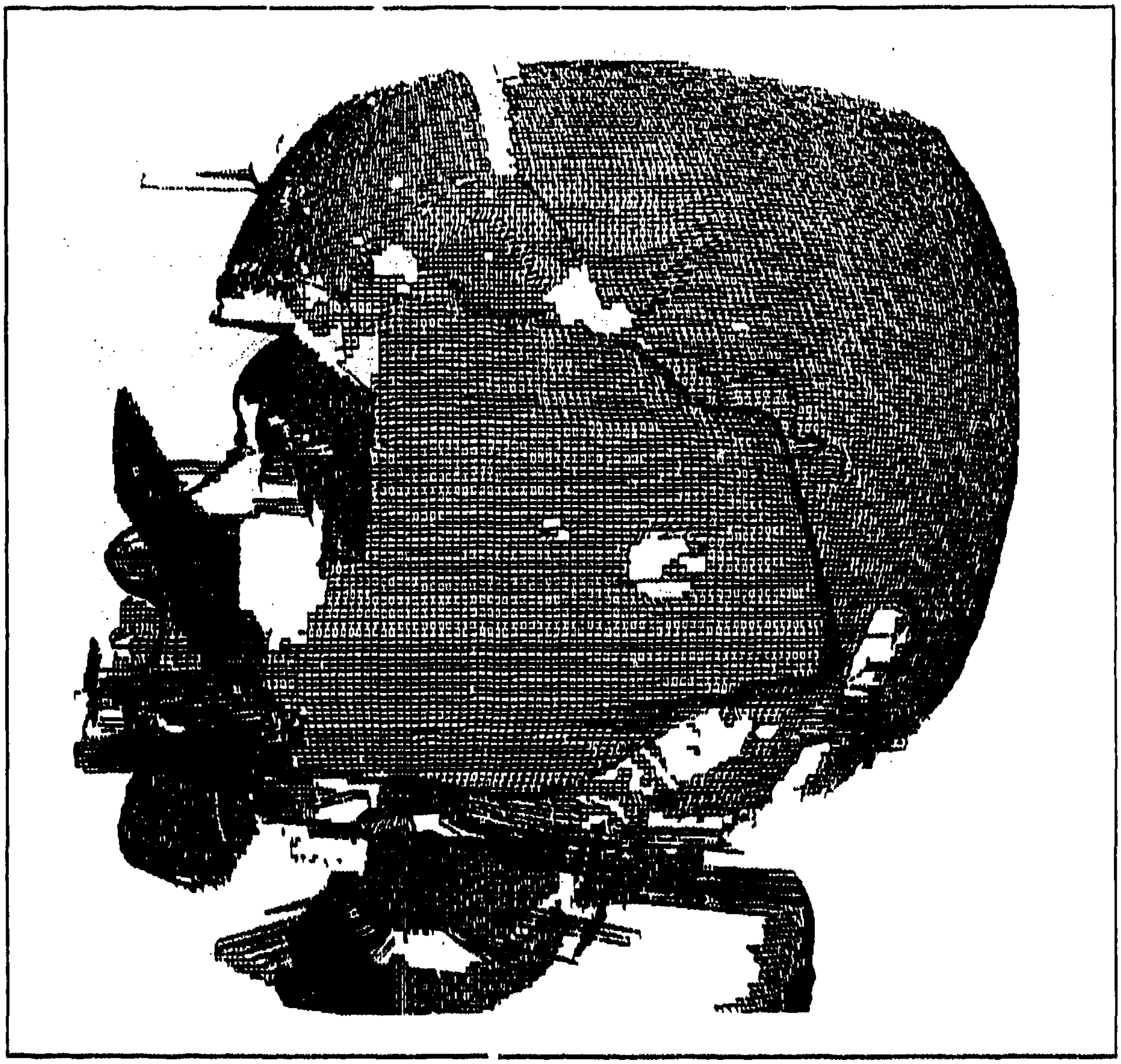


FIGURE 8

3-D Helmet Scan Data

Figure 9 is the anthropometric data sheet. Definitions of the anatomical landmarks are given in Appendix A. The measurement descriptions are listed in Appendix B.

HELMET ASSESSMENT METHODS

Each helmet with an operational optical system was tested for (1) optical placement, (2) stability, and (3) comfort; the mock-ups were tested for stability and comfort only. The information was recorded on the form illustrated in Figure 10.

Optical Placement Assessment

The subject was fit in the first of the three candidate systems, assigned in varying orders. The process began with the correct placement of the subject's helmet liner in the shell of the helmet. The subject then donned the helmet, and the night vision goggles (NVGs) were adjusted to an approximation of the correct position. The helmet was removed in order to allow the investigator to insert and adjust the ear cups. The subject re-donned the system, and was fit in the correct size of the MBU-12/P oxygen mask.

In a darkened room, the NVGs were switched on. The horizontal, vertical, and fore-and-aft positioning of the optical devices, known as combiners, were adjusted until the combiner lenses were as close as possible to the proper position with respect to the subject's eyes. The proper position was achieved when two circular intensified vision fields fused in such a way as to appear to the subject as one fused field. (Two overlapping circles were not acceptable.)

In order to determine proper fore-and-aft position of the combiners, the subject was asked to look through the combiners at infrared light emitting diodes (LEDs) positioned at the extreme left and extreme right of the intensified field. Next, the right combiner was covered and the subject was instructed to look toward the left light. If the left light disappeared from view, the subject was too far from the combiner. If the right light could not be seen, the subject was too close to the combiner. If both the left and right lights were visible at the edge of the field, the left combiner was aligned correctly. Corresponding assessments were then made with the left ocular covered.

Acceptable fore-and-aft lens position was not always achieved since the full range of adjustment did not accommodate every subject. When that was the case, it was noted on the data sheet.

The exit pupil is a term used to describe the location of the focused image in space. If a subject was too close to the combiner lenses then he or she was in front of the exit pupil and the image was formed somewhere behind the eye. This caused a wearer to experience loss in the visual field *opposite the direction* to which he or she looked, and was considered acceptable but undesirable. A subject too far from the combiner lenses was behind the exit pupil and the image, therefore, would be formed in front of the eye. This caused a wearer to experience loss in the visual field *in the direction* to which he or she looked. This was considered unacceptable. When a subject was the correct distance from the combiner lenses, that subject was said to be in the exit pupil, and the image was formed on the pupil itself.

ANTHROPOMETRIC INFORMATION

SUBJECT # ________ DATE ________

NAME: ________ RANK: ________

DATE OF BIRTH: ________ AGE AT LAST BIRTHDAY: ____

PLACE OF BIRTH: (STATE) ____ RACE: W B A H Other

GENDER: M F RATED/NON-RATED

GLASSES: Y N MIL/CIV

NON-HELMET SCAN DATE ________ FILENAME ________

MEASUREMENTS TAKEN WITHOUT CAP (mm):

pupil - top of head ________

tragion - top of head ________

head circ ________

head length ________

head breadth ________

MEASUREMENTS TAKEN WITH CAP (mm):

pupil - top of head	________	head length	________
tragion - top of head	________	head breadth	________
head circ	________	face breadth	________
coronal arc	________	bigonial breadth	________
minimum frontal arc	________	face length	________
subnasale arc	________	nose breadth	________
menton arc	________	ear length	________
submandibular arc	________	ear breadth	________
		IPD	________

HAIR LENGTH FOR FIT TEST:

IN BACK: COLLAR/SHOULDER/LONGER WORN UP/LONGER WORN DOWN
AT EARS: ABOVE EARS/BELOW EARS
SAME AS FITTING? YES NO

IF NOT, HAIR LENGTH FOR LINER FITTING:

IN BACK: COLLAR/SHOULDER/LONGER WORN UP/LONGER WORN DOWN
AT EARS: ABOVE EARS/BELOW EARS

FIGURE 9

The Anthropometric Data Sheet

ADJUSTMENT AND STABILITY QUESTIONS

HELMET______ SUBJECT NO.__________ EARPAD THICKNESS__________
DATE________ DON TIME______________ MASK SIZE_________________

(INVESTIGATOR ANSWER THESE)

A1. HOW EASY/DIFFICULT WERE THE STRAPS TO ADJUST?
1 VERY EASY
2 EASY
3 SATISFACTORY
4 DIFFICULT
5 VERY DIFFICULT

A2. HOW EASY/DIFFICULT WERE THE EAR CUPS TO ADJUST?
1 VERY EASY
2 EASY
3 SATISFACTORY
4 DIFFICULT
5 VERY DIFFICULT

A3. HOW EASY/DIFFICULT WERE THE OPTICS TO ADJUST?
1 VERY EASY
2 EASY
3 SATISFACTORY
4 DIFFICULT
5 VERY DIFFICULT

A4. HOW WELL ARE THE OPTICS ADJUSTED OVER THE EYE FOR

X	1. OUT TOO FAR	2. OK	3. IN TOO FAR
Y	1. NOT WIDE ENOUGH	2. OK	3. NOT NARROW ENOUGH
Z.	1. TOO HIGH	2. OK	3. TOO LOW

S1. PULLING FORWARD (force in front)
FORCE DEFLECTION RESEAT DEFLECTION ________
2 ________
4 ________

S2. ROLLING BACKWARD (force in back)
FORCE DEFLECTION RESEAT DEFLECTION ________
2 ________
4 ________

S3. SIDEWAYS (force on side)
FORCE DEFLECTION RESEAT DEFLECTION ________
2 ________
4 ________

S4. CHECK 6 LEFT DEFLECTION ________ RESEAT DEFLECTION ________

S6. UP DEFLECTION ________ RESEAT DEFLECTION ________

S8. ROTATION RATINGS (1-NONE 2-SLIGHT 3-MODERATE 4-SEVERE 5-EXCESSIVE)

WITH	ABOUT X	1	2	3	4	5	WITH	ABOUT X	1	2	3	4	5
MASK	ABOUT Y	1	2	3	4	5	MASK	ABOUT Y	1	2	3	4	5
ON	ABOUT Z	1	2	3	4	5	HANGING	ABOUT Z	1	2	3	4	5

FIGURE 10

The Fit Assessment Data Form

COMFORT QUESTIONNAIRE

HELMET ________ SUBJECT NO. ________

(INVESTIGATOR ASKS SUBJECT THESE)

C1. HOW DOES THE HELMET FEEL OVERALL?

PART A	PART B
1 EXTREMELY LOOSE	1 COMFORTABLE
2 SOMEWHAT LOOSE	2 SLIGHTLY UNCOMFORTABLE
3 JUST RIGHT	3 MODERATELY UNCOMFORTABLE
4 SOMEWHAT TIGHT	4 SEVERELY UNCOMFORTABLE
5 PAINFULLY TIGHT	5 INTOLERABLE

C2. HOW DO THE EAR CUPS FEEL?

PART A	PART B
1 EXTREMELY LOOSE	1 COMFORTABLE
2 SOMEWHAT LOOSE	2 SLIGHTLY UNCOMFORTABLE
3 JUST RIGHT	3 MODERATELY UNCOMFORTABLE
4 SOMEWHAT TIGHT	4 SEVERELY UNCOMFORTABLE
5 PAINFULLY TIGHT	5 INTOLERABLE

C3. DO YOU FEEL ANY HOT SPOTS? Y N

A. IF YES, WHERE? B. IF YES, HOW SEVERE?

PART A	PART B
A) EARS	1 COMFORTABLE
B) FOREHEAD	2 SLIGHTLY UNCOMFORTABLE
C) CRANIUM	3 MODERATELY UNCOMFORTABLE
D) CHIN STRAP	4 SEVERELY UNCOMFORTABLE
E) NAPE STRAP	5 INTOLERABLE
F) OTHER ________	

C4. ARE YOU EXPERIENCING ANY PRESSURE FROM THE HELMET? Y N

A) IF YES, IS IT
1 COMFORTABLE
2 SLIGHTLY UNCOMFORTABLE
3 MODERATELY UNCOMFORTABLE
4 SEVERELY UNCOMFORTABLE
5 INTOLERABLE

B) ALSO IF YES, WAS THE PRESSURE (CIRCLE ALL THOSE APPLICABLE):
A) SPREAD OUT ALL OVER
B) LOCALIZED AT TOP OF HEAD FRONT
C) LOCALIZED AT TOP OF HEAD BACK
D) LOCALIZED AT SIDE(S) OF HEAD
E) LOCALIZED AT FOREHEAD
F) LOCALIZED AT EARS
G) LOCALIZED AT BACK OF HEAD
H) OTHER specify ________

C5. DO YOU FEEL YOU CAN KEEP YOUR HEAD UP
(IN OTHER WORDS, LOOK STRAIGHT AHEAD)? Y N

C6. DO YOU FEEL YOU CAN KEEP YOUR HEAD STATIONARY? Y N

C7. DO YOU EXPERIENCE ANY NECK DISCOMFORT? Y N
IF YES, HOW MUCH?
1 COMFORTABLE
2 SLIGHTLY UNCOMFORTABLE
3 MODERATELY UNCOMFORTABLE
4 SEVERELY UNCOMFORTABLE
5 INTOLERABLE

C8. DO YOU EXPERIENCE ANY BACK DISCOMFORT? Y N
IF YES, HOW MUCH?
1 COMFORTABLE
2 SLIGHTLY UNCOMFORTABLE
3 MODERATELY UNCOMFORTABLE
4 SEVERELY UNCOMFORTABLE
5 INTOLERABLE

SUBJECT COMMENTS:

INVESTIGATOR COMMENTS:

FIGURE 10 (cont'd)

The Fit Assessment Data Form

If the combiners were situated at some point on the perimeter of the exit pupil (rather than centered in it), the image was dimmer and slight subsequent movement of the helmet system on the head could result in complete loss of the visual image.

After the location of the exit pupil had been recorded (too far, too close, or correctly aligned), the subject was instructed to look up and over first the right, and then the left, shoulder. (These actions are known as "Check-6.") An investigator visually assessed the location of the helmet to ensure that the subject's movement did not change the position of the helmet and therefore, the position of the exit pupil. If a shift in helmet position required repositioning, this was done, and the need for readjustment was indicated on the margin of the subject's data sheet.

General Optical Adjustment Rating

A general optical adjustment rating was devised as a measure of the ability of the optical system of a given helmet to accommodate each test subject. This was recorded in the investigator ratings section at the top of the form shown in Figure 11.

The purpose of questions A1, A2, and A3 (see Figure 10) was to establish the ease with which the straps, ear cups, and optics were adjusted. Responses to these questions yield information useful in helmet design and analysis.

Although question A3 (Figure 10) evaluated the ease with which the optics could be adjusted, it was question A4 (Figure 10) which evaluated the extent to which optical adjustment was achieved for each subject. Such information relates directly to the issue of fit. For this reason, the optical adjustment ratings were based on the responses to question A4, and were established using the following criteria:

1) An excellent rating was assigned whenever the responses to question A4 were "O.K." for the X, Y, and Z axes and when no additional commentary was provided in the margin. The X axis is the horizontal axis running front to back. The horizontal axis running left to right has been defined as the Y axis and the vertical axis as the Z axis. Rotations about the X, Y, and Z axes correspond to roll, pitch, and yaw, respectively.

2) A good rating was assigned whenever the responses to question A4 were "O.K." for all three axes but relevant commentary indicated some problem.

3) An average rating was assigned whenever any one of the following was true:

   a) For the X axis when X=3 with no additional comments.

   b) For the Y axis when Y=1 with no additional comments.

   c) For the Y axis when Y=3 with no additional comments.

   d) For the Z axis when Z=1 with no additional comments.

   e) For the Z axis when Z=3 with no additional comments.

GENERAL INVESTIGATOR RATINGS (1=EXC, 2=GOOD, 3=AVERAGE, 4=FAIR, 5=POOR)

	OPTICAL	COMFORT	STABILITY	OVERALL
HELMET G	______	______	______	______
HELMET H	______	______	______	______
HELMET K	______	______	______	______

SUBJECT RATINGS (1=EXC, 2=GOOD, 3=AVERAGE, 4=FAIR, 5=POOR)

	OPTICAL	COMFORT	STABILITY	OVERALL
HELMET G	______	______	______	______
HELMET H	______	______	______	______
HELMET K	______	______	______	______

SUBJECT COMMENTS:

INVESTIGATOR COMMENTS:

FIGURE 11

The Overall Assessment Information Form

4) A fair rating was assigned whenever the response to question A4 was Z=1 or Z=3 and marginal comments referred to asymmetry along this axis.

5) A poor rating was assigned whenever the response to question A4 was X=1.

Helmet Stability Assessment

The stability assessment consisted of two parts, a subjective and a quantitative evaluation.

Subjective Stability Evaluation. Once the combiners were properly adjusted, the subject was asked to rotate his or her head about the X, Y, and Z axes. Any visible movement of the helmet along any of the three axes was recorded by the investigator on a scale of 1 to 5 with 1 representing the lack of movement and 5 representing excessive movement.

Quantitative Stability Testing. A series of quantitative observations was made with respect to the stability of the helmet. A small cylindrical device approximately the length and diameter of a ball point pen was fashioned for these observations and was attached to the helmet (see Figures 12 and 13). This device, called the helmet deflection indicator (HDI), featured etch marks which were used as reference points for charting the movement of the helmet on each person's forehead. Short marks corresponding to the etch marks on the HDI were drawn directly on the subject's forehead in water-soluble ink, and served as reference points for the stability testing. Forces of two and four pounds were exerted from fore and aft, and from the right side of the helmet. Any helmet displacement at two and at four pounds of pressure was marked directly on the subject's forehead. Also marked was the place to which the helmet reseated when all pressure was released.

After all the necessary marks had been drawn on the test subject's forehead, the HDI was removed. The distances between the marks were measured and recorded on the data form (Figure 10).

General Stability Rating. The overall stability of each system was based on the results of the quantitative stability testing. The numbers reflect helmet movement as observed by the investigator, and do not serve to quantify movement of the optical image seen by a test subject.

1) Movement or reseat deflection of 0.00 - 4.99 mm was given an excellent rating.

2) Movement or reseat deflection of 5.00 - 9.99 mm was given a good rating.

3) Movement or reseat deflection of 10.00 - 14.99 mm was given an average rating.

4) Movement or reseat deflection of 15.00 - 20.00 mm was given a fair rating.

5) Movement of 20.00 mm or more was given a poor rating.

A rating of 1, 2, or 3 (excellent, good, or average) was considered to be a fit "pass" and a rating of 4 or 5 (fair or poor) was considered to be a fit "failure."

FIGURE 12

A Helmeted Test Subject Before Attachment of the Helmet Deflection Indicator, or HDI

FIGURE 13

A Helmeted Test Subject with Helmet Deflection Indicator (HDI) Attached

Comfort Assessment

In order to adequately assess the comfort of these helmet systems, each subject was asked to wear each system continuously for one hour after the necessary optical adjustments had been made. At the end of the one-hour time period, the test subject removed the mask and helmet, and the investigator completed measurements from the marks drawn on the subject's forehead during the stability testing. The investigator then administered the comfort questionnaire, reading the questions and responses to the test subject, and asking the subject to select the appropriate response or responses.

General Comfort Rating. The criteria listed below were used to rate the comfort of each system; ratings were recorded on the data form shown in Figure 10 (page 18).

1) An excellent rating was assigned to a subject whose answers to all questions were "just right" or "comfortable," indicating no discomfort of any sort.

2) A good rating was given to a subject whose form contained one response which indicated "slight" or "moderate" discomfort. Such discomfort would be indicated by any of the following responses: *somewhat tight, slightly uncomfortable,* or *moderately uncomfortable.*

3) An average rating was given to a subject whose form contained two or more responses which indicated "slight" or "moderate" discomfort.

4) A fair rating was given to a subject whose form contained one response which indicated "severe" or "intolerable" discomfort. Such discomfort would be indicated by any of the following responses: *painfully tight, severely uncomfortable,* or *intolerable.*

5) A poor rating was assigned to a subject whose form contained two or more responses which indicated "severe" or "intolerable" discomfort.

Overall Ratings

The final step was to arrive at an overall rating for each element of the assessment for use as a quick summary. Both subjects and investigators rated the helmets using a scale of 1 to 5 (1 = excellent, 2 = good, etc.) The ratings were recorded in the last column on the form shown in Figure 11.

Test Subject Ratings. The subject was asked to assess the system for its optical adjustment capabilities, its comfort, and its stability. The subjects were also asked to give the helmet an overall numerical rating based on their impressions of the system as a whole.

Investigator Ratings. The investigator also provided generalized "fit scores" to summarize each assessment. The overall score was arrived at by selecting the lowest (or worst) numerical rating received in any of the three categories. For example, Subject X, wearing helmet Y, would have an overall score of 4 if he received the following ratings for that helmet:

optics	= 1
stability	= 2
comfort	= 4

An overall score of 1, 2, or 3 was considered to be a fit "pass" and a rating of 4 or 5 a fit "failure." Therefore, Subject X would be described as having unacceptable fit results in helmet Y. While the general ratings by the investigator and the subjects are useful as a summary tool, the detailed data scores should be used when examining relationships between fit and performance during other testing.

RESULTS

Frequency charts for all information on the data forms appear in Appendix C.

The general ratings for optics, stability, comfort, and overall suitability are summarized in Tables 3 and 4. Tables 5-7 provide breakdowns of the results by test group. It is important to note that some test subjects were accommodated in one but not all three helmets, although the helmets were all designated "large." This confirmed an earlier suspicion that all size "large" helmets were by no means the same size.

Subject comments about all three helmets are listed in Appendix D.

THE GEC SYSTEM

Thirty-six of the 37 I-NIGHTS subjects participated in the HMST evaluation of the GEC system. Over 41 percent of those tested failed to achieve an acceptable fit. A review of Table 3 shows that GEC had an obvious problem with optical placement. Nearly 30 percent of those "failures" can be attributed to problems with optical placement. GEC may have been disadvantaged in this area by its method of liner preparation. GEC liner preparation required the presence of a trained GEC representative, so these liners were prepared prior to the fit assessment dates. This eliminated the possibility of form-fitting the GEC liner to the specific helmet to be used by a given subject. Liners for both Honeywell and Kaiser helmets were fitted to the specific helmet used in each fit assessment session and, therefore, those helmets had a distinct advantage over the GEC in helmet placement.

Optical placement is of major importance because less than perfectly placed optics cause dimness in the visual field, and only slight movement frequently causes loss of the visual image. Comments from the test pilots indicate that these problems did occur with the GEC helmet (personal communication with Kim Lokos of 6510th Test Wing/DORN, Edwards AFB, CA).

Specific Optical Problems

Among the optical problems noted were: combiners too low; one or both combiners too far from the eye; combiners too low *and* too far out, and inability to get satisfactory optical adjustment for a subject whose eyes were asymmetrically spaced from the bridge of the nose, because combiners move only simultaneously. These examples suggest that the optics should cover a wider range of adjustment and that each combiner should be adjustable independently.

TABLE 3

Investigator Ratings for All Test Subjects

COMFORT

HELMET	% FAIL	% PASS
GEC	19.4	80.6
HONEYWELL	18.2	81.8
KAISER (NVG)	16.7	83.3
KAISER (HMD)	26.7	73.3

STABILITY

HELMET	% FAIL	% PASS
GEC	17.1	82.9
HONEYWELL	24.2	75.8
KAISER (NVG)	27.8	72.2
KAISER (HMD)	26.7	73.3

OPTICAL PLACEMENT

HELMET	% FAIL	% PASS
GEC	29.6	70.4
HONEYWELL	8.3	91.7
KAISER (NVG)	4.2	95.8
KAISER (HMD)	0.0	100.0

OVERALL

HELMET	% FAIL	% PASS
GEC	41.7	58.3
HONEYWELL	39.4	60.6
KAISER (NVG)	44.4	55.6
KAISER (HMD)	46.7	53.3

TABLE 4

Test Subject Ratings for All Test Subjects

COMFORT

HELMET	% FAIL	% PASS
GEC	27.8	72.2
HONEYWELL	33.3	66.7
KAISER (NVG)	25.7	74.3
KAISER (HMD)	53.3	46.7

STABILITY

HELMET	% FAIL	% PASS
GEC	27.8	72.2
HONEYWELL	33.3	66.7
KAISER (NVG)	25.7	74.3
KAISER (HMD)	53.3	46.7

OPTICAL PLACEMENT

HELMET	% FAIL	% PASS
GEC	25.0	75.0
HONEYWELL	12.1	87.9
KAISER (NVG)	17.6	82.4
KAISER (HMD)	33.3	66.7

OVERALL

HELMET	% FAIL	% PASS
GEC	41.7	58.3
HONEYWELL	36.4	63.6
KAISER (NVG)	37.1	62.9
KAISER (HMD)	66.7	33.3

TABLE 5

Investigator Ratings for Centrifuge Test Subjects

COMFORT

HELMET	% FAIL	% PASS
GEC	25.0	75.0
HONEYWELL	30.0	70.0
KAISER (NVG)	9.1	90.9
KAISER (HMD)	33.3	66.7

STABILITY

HELMET	% FAIL	% PASS
GEC	16.7	83.3
HONEYWELL	40.0	60.0
KAISER (NVG)	18.2	81.8
KAISER (HMD)	0.0	100.0

OPTICAL PLACEMENT

HELMET	% FAIL	% PASS
GEC	33.3	66.7
HONEYWELL	10.0	90.0
KAISER (NVG)	0.0	100.0
KAISER (HMD)	0.0	100.0

OVERALL

HELMET	% FAIL	% PASS
GEC	50.0	50.0
HONEYWELL	50.0	50.0
KAISER (NVG)	27.3	72.7
KAISER (HMD)	33.3	66.7

TABLE 6

Investigator Ratings for Drop Tower Test Subjects

COMFORT

HELMET	% FAIL	% PASS
GEC	36.4	63.6
HONEYWELL	30.0	70.0
KAISER (NVG)	16.7	83.3
KAISER (HMD)	NOT TESTED	

STABILITY

HELMET	% FAIL	% PASS
GEC	10.0	90.0
HONEYWELL	0.0	100.0
KAISER (NVG)	0.0	100.0
KAISER (HMD)	NOT TESTED	

OVERALL

HELMET	% FAIL	% PASS
GEC	45.5	54.5
HONEYWELL	30.0	70.0
KAISER (NVG)	16.7	83.3
KAISER (HMD)	NOT TESTED	

TABLE 7

Investigator Ratings for Pilot Test Subjects

COMFORT

HELMET	% FAIL	% PASS
GEC	0.0	100.0
HONEYWELL	0.0	100.0
KAISER (NVG)	23.1	76.9
KAISER (HMD)	16.7	83.3

STABILITY

HELMET	% FAIL	% PASS
GEC	23.1	76.9
HONEYWELL	30.8	69.2
KAISER (NVG)	61.5	38.5
KAISER (HMD)	66.7	33.3

OPTICAL PLACEMENT

HELMET	% FAIL	% PASS
GEC	15.4	84.6
HONEYWELL	0.0	100.0
KAISER (NVG)	7.7	92.3
KAISER (HMD)	0.0	100.0

OVERALL

HELMET	% FAIL	% PASS
GEC	30.8	69.2
HONEYWELL	38.5	61.5
KAISER (NVG)	84.6	15.4
KAISER (HMD)	66.7	33.3

Discomfort Problems

Other problems with the GEC involved discomfort. Widespread pressure and hot spots occurred, and in many cases, the source of the problem seemed to be the liner rather than the fit of the helmet itself. For this reason, GEC may want to rethink the type of liner it makes, and/or the material from which the liner is made.

Accommodation Problems

Data from several subjects indicate that those who combine long head lengths and narrow head breadths are not well accommodated by GEC helmets. In these cases, when the helmet was correctly placed and the optics were correctly aligned, the front edge of the helmet, which should have cleared the brow, instead rested upon it. This caused pressure on the brow which was usually unbearable. There is no indication whether the problem originates in the design of the helmet shell, or in the design and placement of the liner.

It is interesting that this problem was not encountered by subjects with long head lengths and wide head breadths although it would be logical to expect more of this type of problem with this group. The data suggest that the difference may be attributed to the shape of the head (rather than its size).

THE HONEYWELL SYSTEM

Thirty-three subjects participated in the HMST evaluation of the Honeywell system. Almost 40 percent of the helmets tested on those subjects were failures. The results in Table 3 show that instability was responsible for the problem in approximately 25 percent of the cases. Initial optical placement for the Honeywell helmet was good (8.3% failure) but problems encountered with stability tend to obviate an apparently good optical fit since an unstable helmet moving around the head will misalign the optics.

Instability for Honeywell is an area of concern not just because of the frequency of the problem, but because of its extent. At 4 lbs. of pressure (from the back), the HDI attached at the center of the forehead, ran all the way down the length of one subject's nose, until it passed over the end of his nose and lost contact with the surface of his face. The amount of movement was roughly 62 mm before contact was lost. In another case, the device was attached to the left of the center of the forehead. Also at 4 lbs. of pressure from the back, the device rolled down the forehead, over the eyelid, and down the cheek until it rounded the curve of the cheekbone and lost contact with the surface of the skin somewhere on the lower left cheek. Movement here was approximately 75 mm until contact was lost.

Comfort Problems

A number of subjects tested in the Honeywell system experienced comfort-related failures because the shell of the helmet was too tight. Five of those seven failures also involved serious problems with ear cups which were too tight. The resulting pressure was, at a minimum, severely uncomfortable, causing painful hot spots everywhere: on the ears, above the ears, behind the ears, on the forehead, on both the right and left sides of the head, and at the hinge of the jaw.

Spectacles

Of the five test subjects who wore glasses (the HGU-4/P spectacles) during the fit evaluation, two were not acceptably accommodated due to those eyeglasses. In one case, it was possible to properly position both of the combiners, but the combiners pressed the glasses into the forehead and the bridge of the nose. The subject withstood the resulting pressure for about 45 minutes, but the extent of the pain would have impeded optimum performance in an operational environment.

THE KAISER SYSTEM

Thirty-six subjects were a part of the HMST fit assessment of the Kaiser system. Forty-five percent of the helmets tested on those subjects were failures. Table 3 shows that Kaiser averaged a 97.9 percent pass rate for optical placement, yet some 45 percent of the subjects assessed in this system were not well fit by this helmet. As with Honeywell, instability was largely responsible, and it bears mentioning that instability was a problem not only in frequency but also in extent. Table 8 illustrates the severity of the problem:

TABLE 8

Incidences of Instability in the Kaiser Helmet System
(pressure in lbs; movement and deflection in mm)

TEST SUBJECT NUMBER	AMOUNT OF PRESSURE	DEGREE OF MOVEMENT	RESEAT DEFLECTION
5	4	16	9
7	4	25	21
26	4	33	30
30	4	61	42
31	4	22	17
35	4	21	13
44	4	38	27

Comfort Problems

Discomfort was a concern as well. Subjects experienced painful pressure and severe hot spots all over the head. One test subject could not wear the system for more than 30 minutes. Other comfort-related issues for the Kaiser system were weight and weight distribution. Seven people commented that the helmet weight was "too far forward." Six of the seven said that the load needed to be "centered" and one suggested that a "more functional nape strap" be added to help counterbalance the load. All of these subjects experienced slight to moderate neck discomfort in the course of the hour.

DISCUSSION AND RECOMMENDATIONS

RESULTS SUMMARY

The results of the fit assessment indicate key areas of concern for the I-NIGHTS helmets.

GEC

For GEC, the major concern is optical placement. The GEC method of liner preparation and helmet placement may play a role in this. Because helmet placement is critical to optical placement and therefore, optical performance, GEC may wish to reconsider its current method of liner preparation in order to improve the optical placement results.

The GEC helmet was praised for the strap adjustments on the ear cups and at the nape of the neck. These adjustment methods were considered superior by many of the test subjects.

Several of the subjects commented that GEC should add combiner stowing capabilities to their helmet.

Honeywell

The data for the Honeywell helmet indicate that the main area of concern was stability. Test subject comments that the helmet was "too loose front to back, but too tight side to side" as well as the occurrence of numerous hot spots around the ear and on the side of the head indicate that Honeywell might want to consider some redesign of the shape of its helmet.

The Honeywell optics provided excellent visual clarity when the optical system was inactive. The level of visual clarity diminished somewhat when the system was activated because of helmet instability, but overall the quality of the optics was considered good.

Kaiser

The Kaiser helmet data show frequent and extreme instances of instability. Comments from the test subjects (see Appendix D) reveal that the weight of the helmet is not well distributed. Many of the subjects further complained that the helmet felt heavy due to poor weight distribution. Poor weight distribution may also be a factor contributing to the instability of the helmet. Kaiser might be well advised to examine this problem and consider whether redistributing the weight of the helmet would improve the stability of the system as a whole.

The optical adjustment system of the Kaiser helmet was considered outstanding by the test subjects. They were particularly impressed with the flip-up method of stowing the combiners. Considered equally impressive was the level of visual clarity in the Kaiser optical system.

HELMET LINERS

A helmet with integrated NVG or HMD can be from 2 to 3 pounds heavier than a standard helmet, and the extra weight contributes to problems of instability and discomfort.

Because the liner is integral to stability and comfort, anyone designing an integrated helmet must carefully consider the liner early in the design phase both with regard to the liner preparation method, and liner material. GEC creates liners by injecting foam into a molding tool. The Kaiser and Honeywell methods involve the creation of generic liners which soften when heated and can be molded in the test helmet when the subject is wearing it.

It would be to a vendor's advantage to form the liner in the test helmet rather than forming it in a molding tool because the liner formed in the actual helmet tends to fit better. This, in turn, facilitates comfort and stability. Also, forming the liner in the test helmet permits optical adjustment because the liners are formed while the subject holds the helmet in the "best" location. A liner formed in a molding tool may provide a fit customized to the subject's head but not to individual helmets.

The liner material is also important. A liner made from a material which is too hard or brittle may not provide the necessary cushioning between the hard interior surfaces of the helmet and the subject's head and could result in extreme discomfort. A liner which is too soft or spongy may not provide the necessary stability and can result in greatly diminished optical performance.

HELMET SIZING

Results of this research indicate that identically named sizes vary, and that it is generally incorrect to assume that "a large is a large is a large." Because it would be useful to test comparably sized helmets, future test designers may wish to define sizes better for vendors.

The most effective way to address this type of fit testing program would be to (1) begin with one size, (2) determine the range of fit for that size, and (3) develop other sizes. For design purposes, the report by Robinette and Whitestone (1992) may provide useful information because it offers new approaches to characterizing the human head during the design process.

Initial Size

While it is reasonable to begin a fit assessment program with one size of a test item, it is not realistic to expect one size to fit all users. The goal in selecting the first size should be to attempt to accommodate as much of the user population as possible. The I-NIGHTS approach involved use of a size "large." The logic behind that decision was that the large size could accommodate more of the user population than smaller sizes because the "large" should accommodate users with larger heads, and that padding (in the form of crown pads and extra padding to build up the ear cups) would provide adequate compensation for the smaller sized heads.

The results of the fit assessments reinforce the concept that one size helmet (in this case, a "large") should not be expected to fit all users. It may have been more realistic to start with a helmet designed to fit a sample near the median (closer to the center of the anthropometric distribution) for helmet design. A "medium" sized helmet may actually accommodate a larger percentage of the user population than can a modifiable "large" because the population is concentrated near the center. Furthermore, test subjects are more likely to be drawn from this size category. Therefore, future researchers may want to choose a "medium" size as the initial size to be tested.

Range of Fit

Once the first size has been determined, it is necessary to assess the fit of that size on a sample of the target population. The assessment results should make it possible to establish a range of fit for the selected size. The range of fit identifies which portion of the user population can be accommodated by that size and should serve as a foundation for the development of other sizes.

Other Sizes

In order to establish an effective sizing method, the designer must have some understanding of the population to be accommodated by the helmet. Having determined the range of fit for the first size, the designer should be able to establish a sizing method whereby he or she can estimate with some certainty the total number of sizes needed to accommodate the entire population, and to define the perimeters of each size. Determining the number of sizes needed to accomplish a fit-related goal is especially important for the Air Force, where it is cost effective to fit as many individuals as possible in as few sizes as possible.

COMBINER ADJUSTMENTS

Optical placement adjustment criteria should include the stipulation that optical devices or combiners must have adjustment capabilities along the X, Y, and Z axes which are independent for each eye. The GEC optical adjustments were independent along two of the three axes but not along the third. Results from this study show that GEC was plagued by optical adjustment limitations along the Y axis (IPD adjustment[1]).

SPECTACLE COMPATIBILITY

It would be useful to examine the compatibility of integrated NVG/HMD helmets with more users or test subjects who wear eyeglasses. Fit problems that were encountered with some of the test subjects wearing eyeglasses may indicate the need for such a study. This study would use the spectacles issued by the U.S. Air Force at the time of the study.

STABILITY TESTING

One factor that was not examined here is the effect of the MBU-12/P mask on the stability of the helmets. Results of subjective stability tests conducted with the mask in place, and with the mask hanging, indicate that the mask may indeed affect the stability of the helmets. This factor bears further investigation.

Another factor related to the balance and stability of the helmets is the visor assembly. Each of the I-NIGHTS helmets was tested with the visor in the stowed (or "up") position. It has not been demonstrated whether a visor placed in the down position would have any effect

[1] Interpupillary Distance (IPD) is the straight-line distance between the centers of the pupils. The IPD adjustment on a helmet allows movement of the combiners along that line (the Y axis).

on the stability of the system. The ease of visor movement (from "up" to "down") should also be evaluated in future studies of this type.

STRAP RELEASE

Test results suggest that vendors would be well advised to design their helmets with the chin strap release on the right side of the helmet. The strap release of the HGU-55/P helmet to which flight crew are accustomed, is on the right side, so the tendency will be to favor the helmet(s) with the release on the right-hand side. In order to facilitate the "mask hanging" exercises of the stability testing (Figure 10, question S8), the oxygen mask release should also be on the right side of the helmet.

REFERENCES

Blackwell, S., I. Tebbetts, J. Crist and G. Zehner. (In Press). *Head and Face Surface Anthropometry of USAF Aviators*. Human Engineering Division, Crew Systems Directorate, Armstrong Laboratory, Wright-Patterson Air Force Base, Ohio.

Gifford, E.C., J.R. Provost and J. Lazo. 1965. *Aerospace Crew Equipment Laboratory Anthropometry of Naval Aviators - 1964*. Report No. NAEC ACEL 533. U.S. Naval Air Engineering Center, Philadelphia, Pennsylvania.

Gordon, C.C., B. Bradtmiller, C. Clauser, T. Churchill, J.T. McConville, I. Tebbetts and R. Walker. 1989. *1987-1988 Anthropometric Survey of U.S. Army Personel: Methods and Summary Statistics*. Technical Report NATICK/TR-89-044. U.S. Army Natick Research Development and Engineering Center, Natick, Massachusetts.

Kennedy, K.W. 1986. *A Collation of United States Air Force Anthropometry*. Armstrong Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio.

Robinette, K.M. and J.J. Whitestone. 1992. *Methods for Characterizing the Human Head for the Design of Helmets*. AL-TR-1992-0061. Human Engineering Division, Crew Systems Directorate, Armstrong Laboratory, Wright-Patterson Air Force Base, Ohio.

APPENDIX A

THE LANDMARKS

FRONTOTEMPORALE (right and left): the point of the deepest indentation of the temporal crest from the frontal bone above the browridges. This is located by palpation.

GLABELLA: the anterior point on the frontal bone midway between the browridges. The investigator stands on the right side and locates the landmark by inspection. Once the dot is drawn, the investigator checks the landmark from the front by visual inspection and adjusts the mark if it is not at midpoint.

GONION: (right and left): the lateral point on the posterior angle of the mandible (jaw bone). This is located by palpation.

MENTON: the lowest point on the mandible (bottom of the chin) in the midsagittal plane. This is located by palpation.

SELLION: the point of the deepest depression of the nasal bones at the top of the nose. This is not palpated or marked on the subject but is located by visual inspection during the computerized landmarking procedure when the data set is turned to a right profile.

SUBMANDIBULAR: the point in the midsagittal plane where the lower jaw joins the neck. (This is sometimes defined as the juncture of the plane of the neck and the plane of the chin, located in the midsagittal plane.) This is marked with a short horizontal line after it is located by visual inspection. Since the horizontal line is not visible on a scan, this point is relocated by visual inspection during the computerized landmarking procedure when the data set is turned to show the right profile.

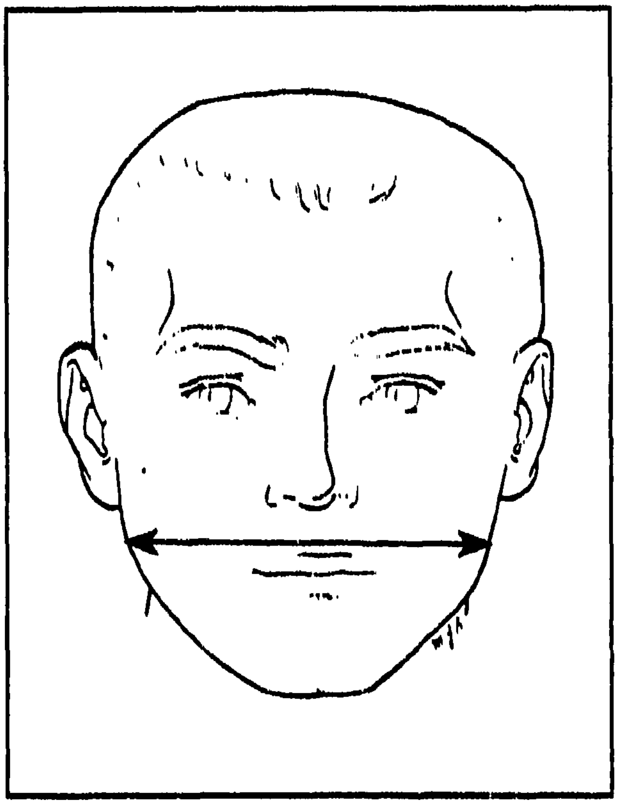
SUBNASALE: the point of intersection of the groove of the upper lip (the philtrum) with the inferior surface of the nose in the midsagittal plane. This is located by visual inspection during the computerized landmarking procedure when the data set is turned to a right profile.

TRAGION (right and left): the superior point on the juncture of the cartilaginous flap of skin (the tragus) of the ear with the head. This is located by palpation.

ZYGION (right and left): the lateral point on the zygomatic arch. It is located by palpation and by using a spreading caliper.

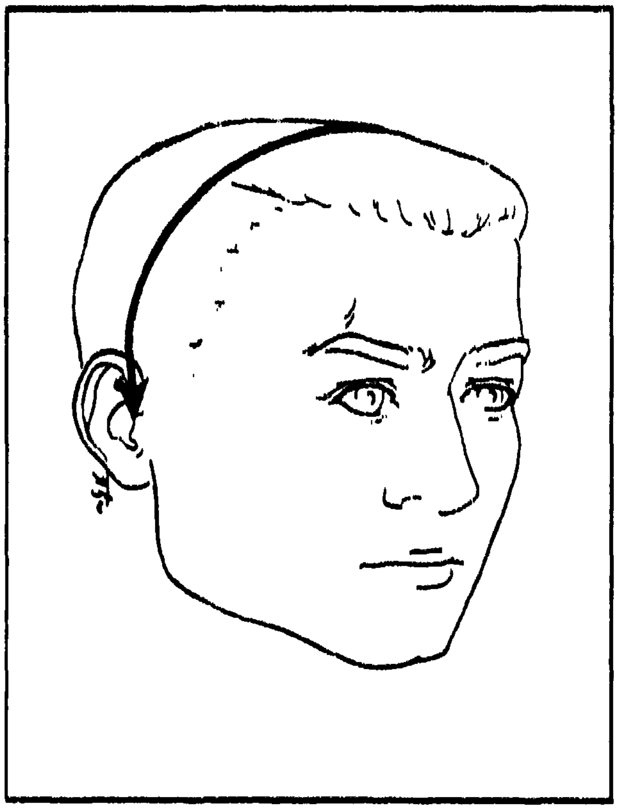
APPENDIX B

I-NIGHTS ANTHROPOMETRY: THE MEASUREMENTS



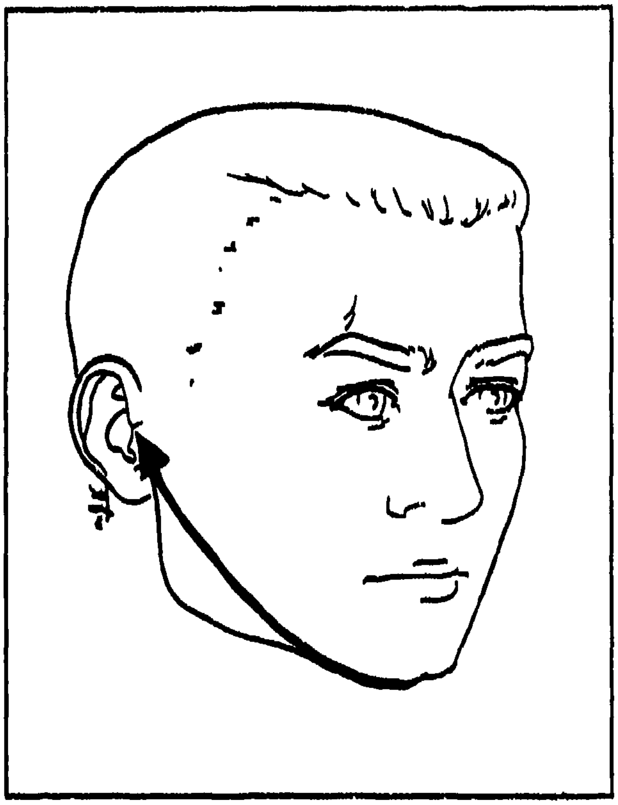
Bigonial Breadth: The straight-line distance between right and left gonion landmarks. This measurement is taken with a spreading caliper.

Landmark(s): Gonion (right and left)



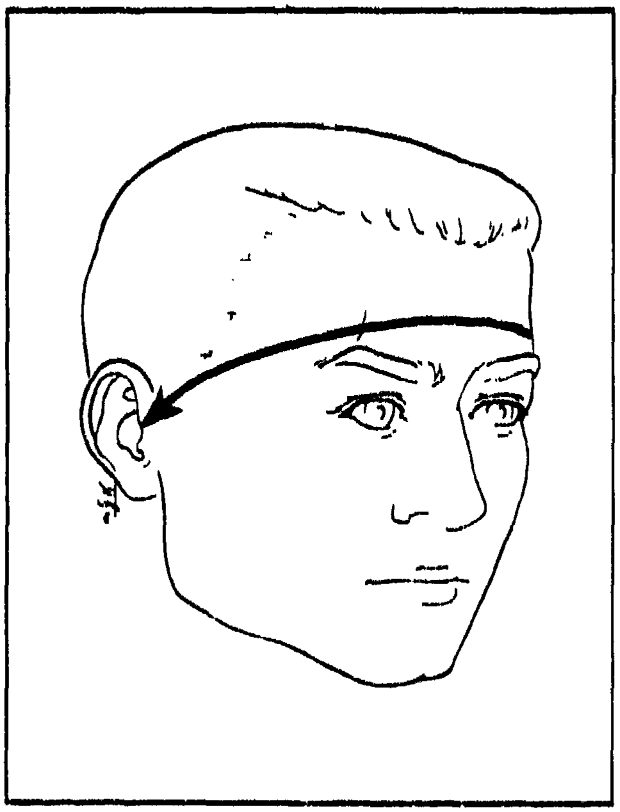
Bitragion-Coronal Arc: The surface distance between right tragion and left tragion across the top of the head in the coronal plane (a plane perpendicular to the floor). This measurement is taken with a tape measure.

Landmark(s): Tragion (right and left)



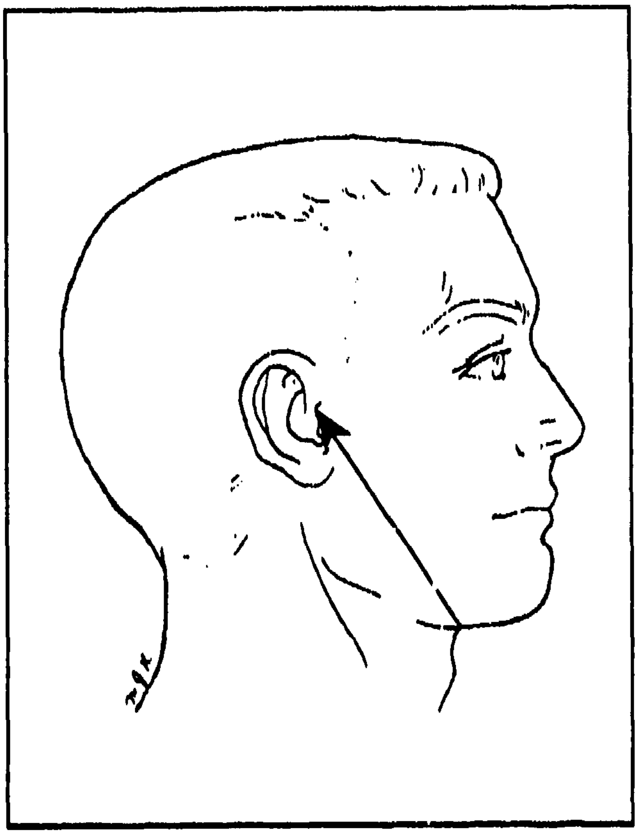
Bitragion-Menton Arc: The surface distance between right tragion and left tragion passing through the menton landmark at the bottom of the chin. This measurement is taken with a tape measure.

Landmark(s): Tragion (right and left), menton



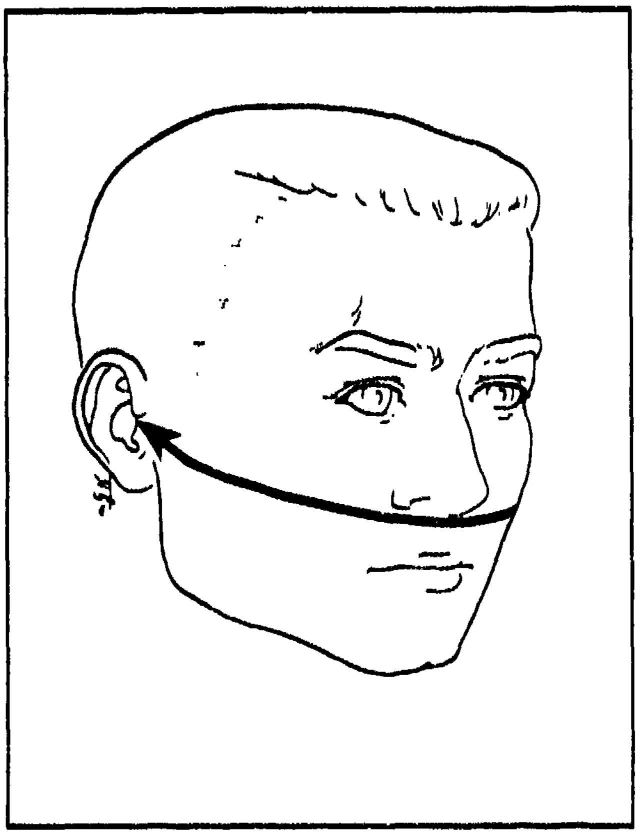
Bitragion-Minimum Frontal Arc: The surface distance between right tragion and left tragion across the forehead and passing over right and left frontotemporale. This measurement is taken with a tape measure.

Landmark(s): Tragion (right and left), frontotemporale (right and left)



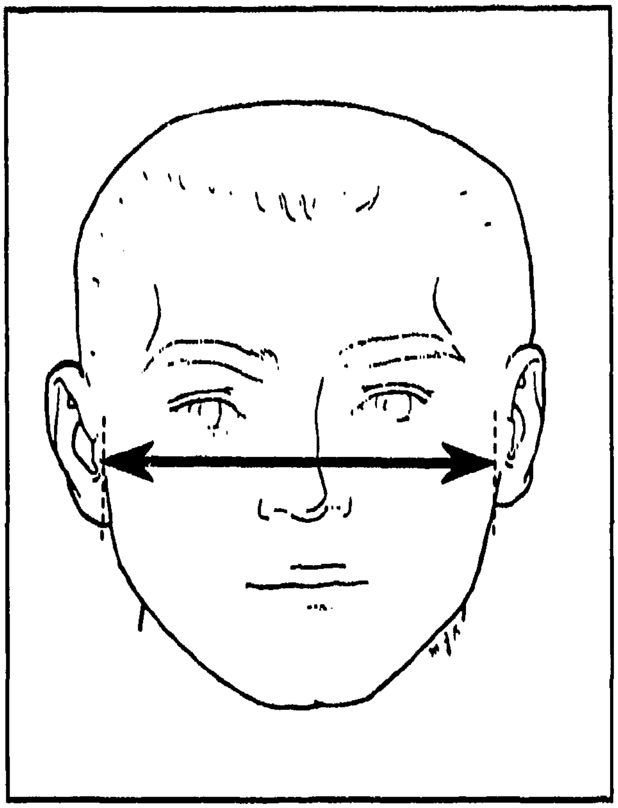
Bitragion-Submandibular Arc: The surface distance between right tragion and left tragion passing through the submandibular landmark at the juncture of the mandible (jaw) and neck. It is important to note that the subject's head must be in the Frankfort Plane. This measurement is taken with a tape measure.

Landmark(s): Tragion (right and left), submandibular



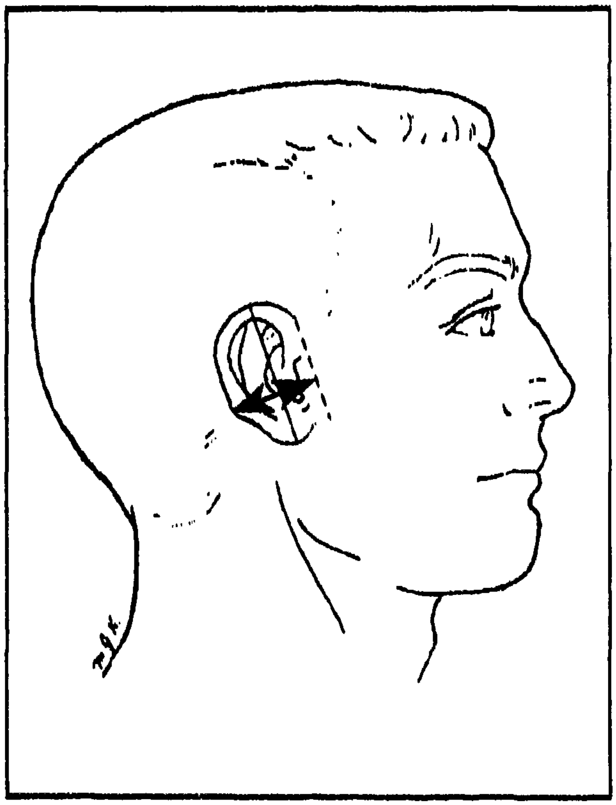
Bitragion-Subnasale Arc: The surface distance between right tragion and left tragion across the subnasale landmark just under the nose. This measurement is taken with a tape measure.

Landmark(s): Tragion (right and left), subnasale



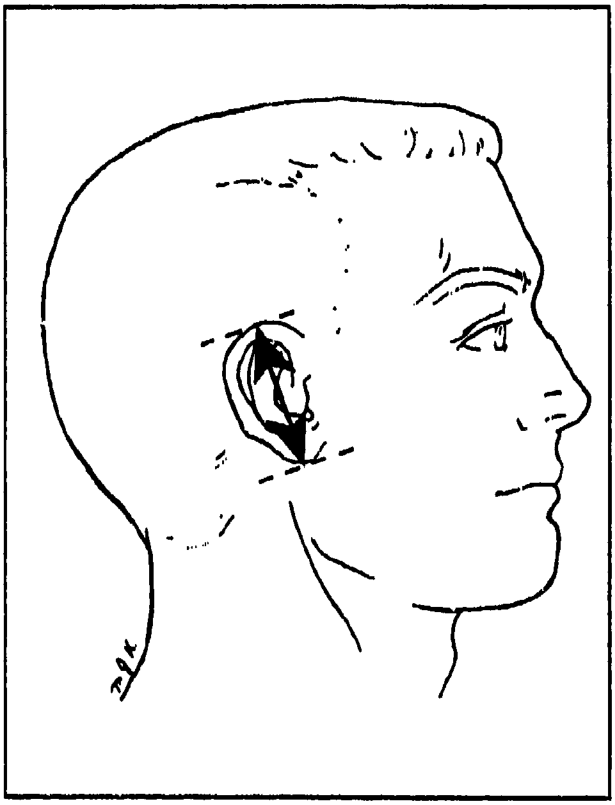
Bizygomatic Breadth (Face Breadth): The straight line distance between the right and left zygion landmarks. This measurement is taken with a spreading caliper.

Landmark(s): Zygion (right and left)



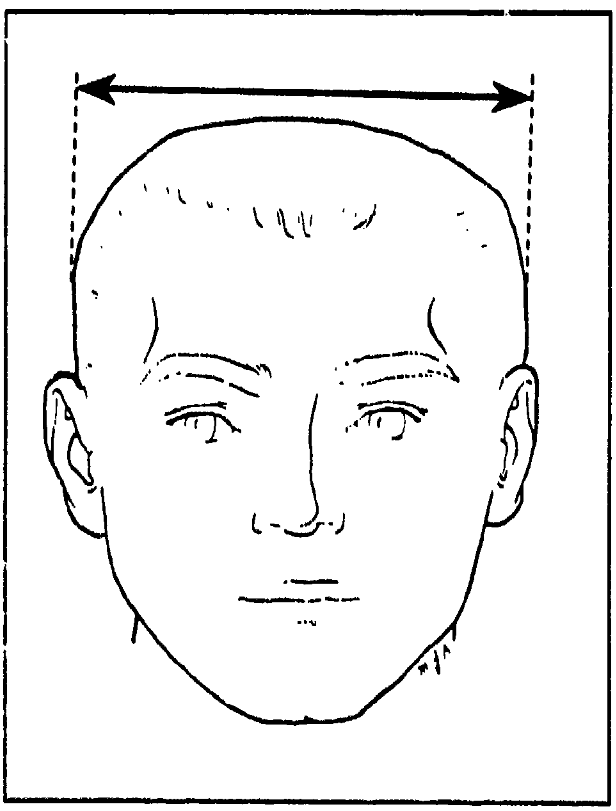
Ear Breadth: The maximum breadth of the right ear perpendicular to its long axis. This measurement is taken with a sliding caliper.

Landmark(s): None



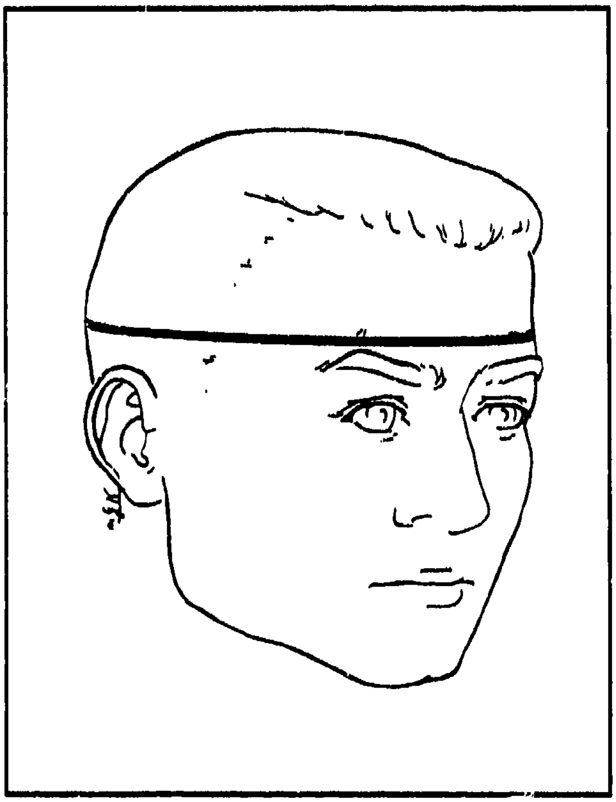
Ear Length: The length of the ear from its highest to lowest points on a line parallel to the long axis of the ear. This measurement is taken with a sliding caliper.

Landmark(s): None



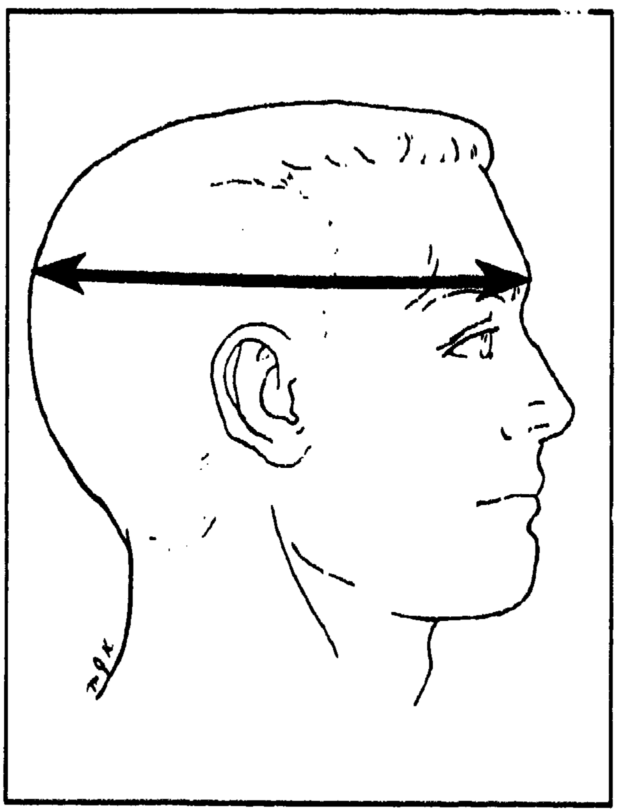
Head Breadth: The maximum horizontal breadth of the head taken above the ears (usually slightly above and behind the ears). This measurement is taken from the rear of the subject with the spreading calipers.

Landmark(s): None



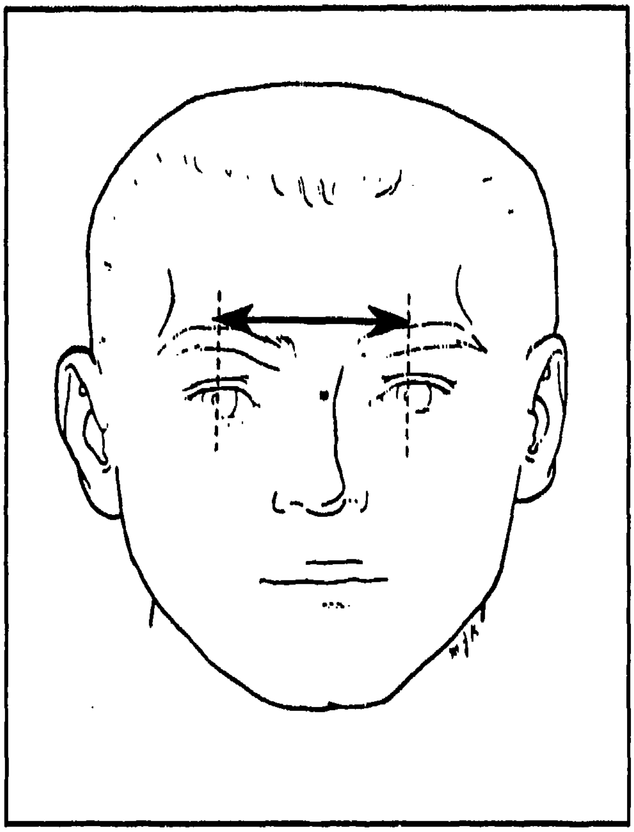
Head Circumference: The maximum circumference of the head above the browridges. This measurement is taken with a tape measure.

Landmark(s): None



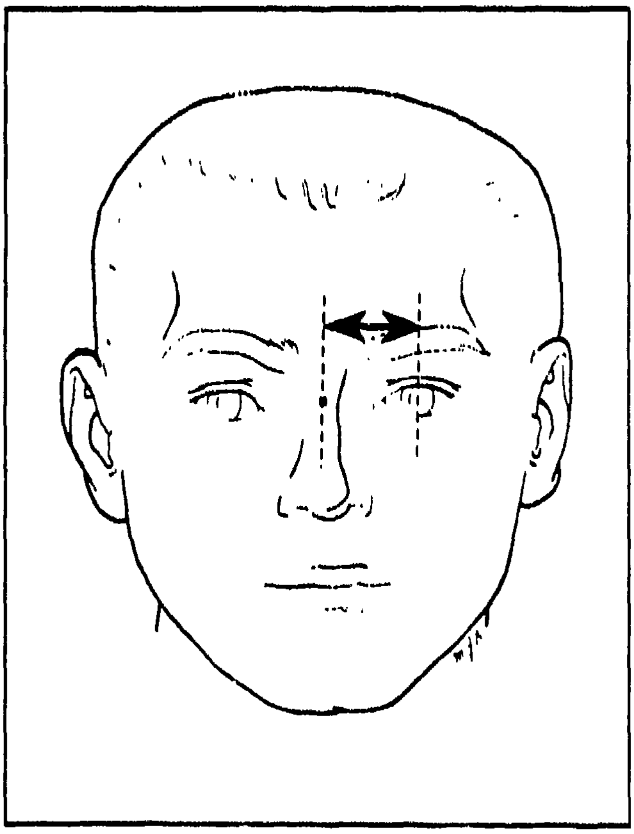
Head Length: The distance from glabella to the most posterior point of the back of the head. This measurement is taken with a spreading caliper.

Landmark(s): Glabella



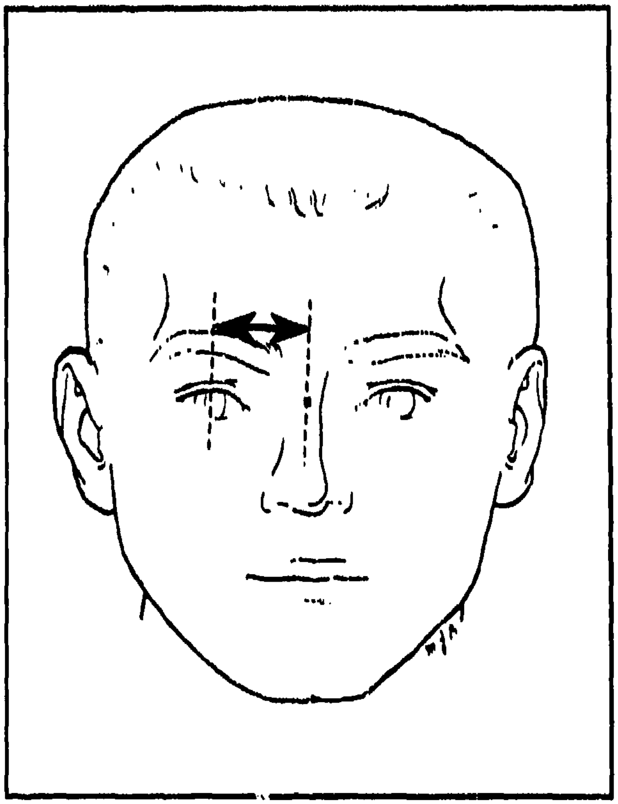
Interpupillary Distance (IPD): Distance between the two pupils. This measurement is taken with a pupillometer.

Landmark(s): Pupil (right and left)



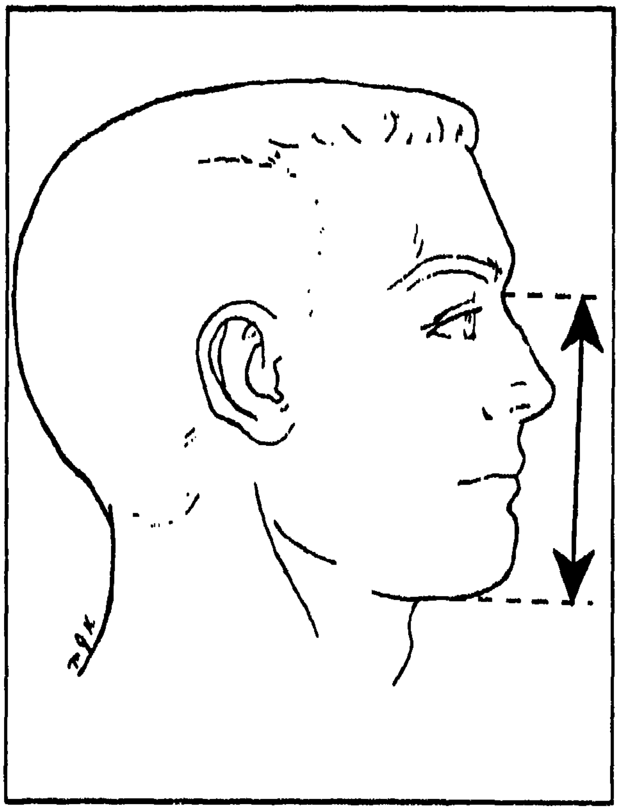
IPD - Left: Distance from the left pupil to a point in the middle of the nasal depression (sellion). The measurement is taken with a pupillometer.

Landmark(s): Pupil (left), sellion



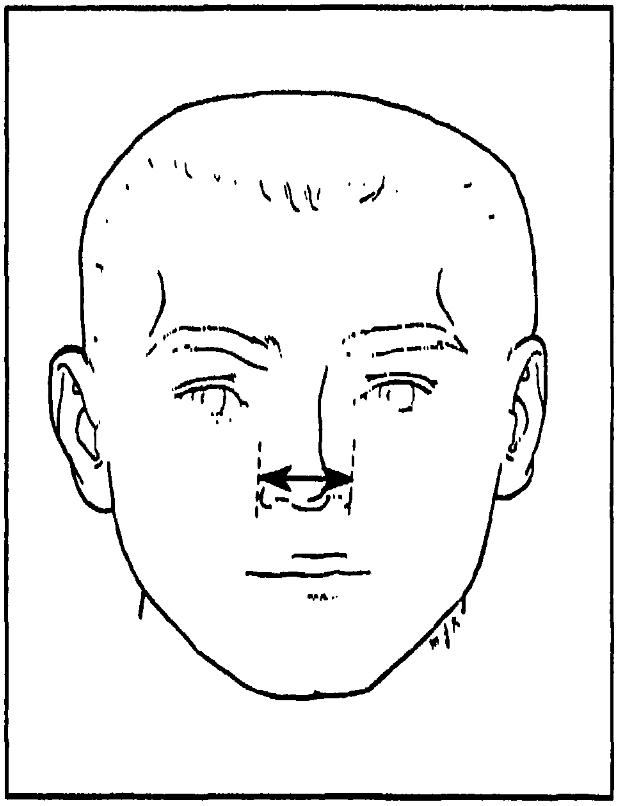
IPD - Right: Distance from the right pupil to a point in the middle of the nasal depression (sellion). The measurement is taken with a pupillometer.

Landmark(s): Pupil (right), sellion



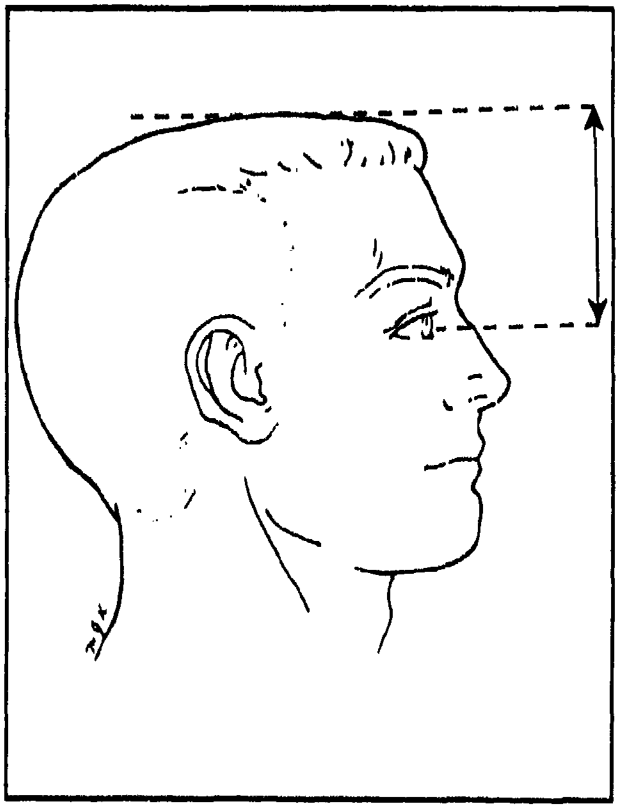
Menton-Sellion Length (Face Length): The vertical distance between menton and sellion. This measurement is taken with a sliding caliper.

Landmark(s): Menton, sellion



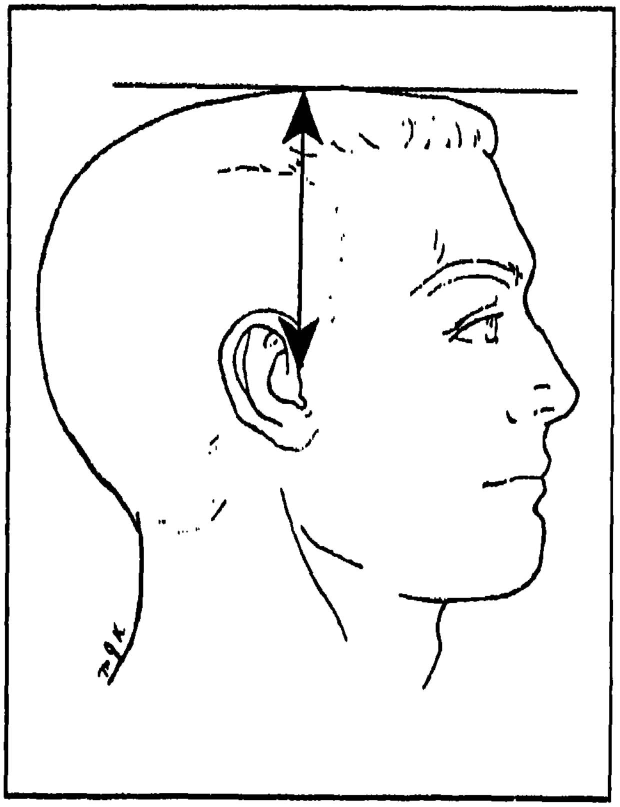
Nose Breadth: The distance between the widest points of the flare of the nose. The measurement is taken with a sliding caliper.

Landmark(s): None



Pupil-Top of Head: The vertical distance from the level of the pupil to the most superior point of the top of the head. The subject is instructed to anchor one blade of the caliper at sellion and then to look straight ahead. The investigator sights pupil level and aids the subject in raising or lowering the anchored end to the appropriate height. The investigator then lowers the other blade of the caliper until it is in contact with the top of the head. This measurement is taken with a beam caliper.

Landmark(s): Sellion, Pupil (right)



Tragion-Top of Head: The vertical distance from the right tragus to the most superior point of the top of the head. This measurement is taken with a beam caliper.

Landmark(s): Tragion (right)

APPENDIX C

FIT EVALUATION RESULTS

TABLE C-1

I-NIGHTS Adjustment Data by Helmet Type

	GEC Freq	GEC %	HON Freq	HON %	KAI-NVG Freq	KAI-NVG %	KAI-HMD Freq	KAI-HMD %
EASE OF STRAP ADJUSTMENT								
Excellent	1	4.0	0	0.0	0	0.0	0	0.0
Good	1	4.0	1	4.3	0	0.0	0	0.0
Average	22	88.0	22	95.7	24	100.0	15	100.0
Fair	1	4.0	0	0.0	0	0.0	0	0.0
Poor	0	0.0	0	0.0	0	0.0	0	0.0
Frequency Missing	12		14		13		22	
EASE/EARCUP ADJUSTMENT								
Excellent	0	0.0	0	0.0	0	0.0	0	0.0
Good	2	8.0	0	0.0	0	0.0	0	0.0
Average	23	92.0	23	100.0	23	95.8	14	93.3
Fair	0	0.0	0	0.0	1	4.1	1	6.7
Poor	0	0.0	0	0.0	0	0.0	0	0.0
Frequency Missing	12		14		13		22	
EASE/OPTICAL ADJUSTMENT								
Excellent	0	0.0	0	0.0	0	0.0	0	0.0
Good	1	4.0	1	4.3	0	0.0	0	0.0
Average	23	92.0	22	95.7	24	100.0	15	100.0
Fair	1	4.0	0	0.0	0	0.0	0	0.0
Poor	0	0.0	0	0.0	0	0.0	0	0.0
Frequency Missing	12		14		13		22	
OPTICAL ADJ FOR X-AXIS								
Excellent	6	24.0	1	4.2	0	0.0	0	0.0
Good	18	72.0	23	95.8	22	91.7	15	100.0
Average	1	4.0	0	0.0	2	8.3	0	0.0
Fair	0	0.0	0	0.0	0	0.0	0	0.0
Poor	0	0.0	0	0.0	0	0.0	0	0.0
Frequency Missing	12		13		13		22	
OPTICAL ADJ FOR Y-AXIS								
Excellent	1	4.0	2	9.1	0	0.0	1	6.7
Good	24	96.0	18	81.8	24	100.0	14	93.3
Average	0	0.0	2	9.1	0	0.0	0	0.0
Fair	0	0.0	0	0.0	0	0.0	0	0.0

	GEC Freq	GEC %	HON Freq	HON %	KAI-NVG Freq	KAI-NVG %	KAI-HMD Freq	KAI-HMD %
Poor	0	0.0	0	0.0	0	0.0	0	0.0
Frequency Missing	12		15		13		22	
OPTICAL ADJ FOR Z-AXIS								
Excellent	0	0.0	0	0.0	2	8.3	0	0.0
Good	24	96.0	23	100.0	22	91.7	15	100.0
Average	1	4.0	0	0.0	0	0.0	0	0.0
Fair	0	0.0	0	0.0	0	0.0	0	0.0
Poor	0	0.0	0	0.0	0	0.0	0	0.0
Frequency Missing	12		14		15		22	

TABLE C-2

GEC
Forward Deflection of Helmet: 2-lb Force

DEFLECTED (mm)	FREQUENCY	PERCENT
1	3	9.1
1.5	1	3.0
2	10	30.3
2.5	1	3.0
3	7	21.2
3.5	1	3.0
4	4	12.1
5	2	6.1
5.5	2	6.1
6	2	6.1

Frequency Missing = 4

TABLE C-3

GEC
Forward Deflection Helmet: 4-lb Force

DEFLECTED (mm)	FREQUENCY	PERCENT
2	3	9.1
3	2	6.1
4	6	18.2
4.5	1	3.0
5	4	12.1
6	4	12.1
7	5	15.2
8	2	6.1
9	2	6.1
10	1	3.0
11	1	3.0
15.5	1	3.0
19	1	3.0

Frequency Missing = 4

TABLE C-4

GEC
Forward Deflection Reseat Position with Force Removed

DEFLECTED (mm)	FREQUENCY	PERCENT
0	6	18.8
1	7	21.9
1.5	3	9.4
2	3	9.4
2.5	1	3.1
3	4	12.5
4	3	9.4
5	2	6.3
7.5	1	3.1
9	2	6.3

Frequency Missing = 5

TABLE C-5

GEC
Backward Deflection of Helmet: 2-lb Force

DEFLECTED (mm)	FREQUENCY	PERCENT
0	1	2.9
1	1	2.9
1.5	1	2.9
2	4	11.8
3	7	20.6
4	5	14.7
5	6	17.6
5.5	1	2.9
6	3	8.8
7	1	2.9
8	1	2.9
9	1	2.9
11	2	5.9

Frequency Missing = 3

TABLE C-6

GEC
Backward Deflection of Helmet: 4-lb Force

DEFLECTED (mm)	FREQUENCY	PERCENT
1	1	3.1
3	1	3.1
3.5	1	3.1
4	4	12.5
5	5	15.6
7	6	18.8
8	3	9.4
9	4	12.5
10	2	6.3
11	1	3.1
12	1	3.1
16	3	9.4

Frequency Missing = 5

TABLE C-7

GEC
Backward Deflection Reseat Position with Force Removed

DEFLECTED (mm)	FREQUENCY	PERCENT
-1	1	3.0
0	5	15.2
1	4	12.1
2	2	6.1
3	6	18.2
3.5	1	3.0
4	5	15.2
5	2	6.1
6	2	6.1
7	1	3.0
8	1	3.0
10	2	6.1
10.5	1	3.0

Frequency Missing = 4

TABLE C-8

GEC
Right Deflection of Helmet: 2-lb Force

DEFLECTED (mm)	FREQUENCY	PERCENT
1	1	2.9
2	10	28.6
2.5	1	2.9
3	7	20.0
3.5	1	2.9
4	10	28.6
4.5	1	2.9
5	2	5.7
6	1	2.9
8	1	2.9

Frequency Missing = 2

TABLE C-9

GEC
Right Deflection of Helmet: 4-lb Force

DEFLECTED (mm)	FREQUENCY	PERCENT
3	2	5.7
4	2	5.7
4.5	1	2.9
5	6	17.1
6	6	17.1
6.5	1	2.9
7	4	11.4
7.5	1	2.9
8	3	8.6
10	3	8.6
12	4	11.4
13	1	2.9
21	1	2.9

Frequency Missing = 2

TABLE C-10

GEC
Right Deflection Reseat Position with Force Removed

DEFLECTED (mm)	FREQUENCY	PERCENT
-1	1	2.9
0	2	5.7
1	7	20.0
1.5	2	5.7
2	9	25.7
2.5	1	2.9
3	7	20.0
4	1	2.9
6	2	5.7
7	2	5.7
11	1	2.9

Frequency Missing = 2

TABLE C-11

GEC
Deflection of Helmet: Subject in "Check-6" Position

DEFLECTED (mm)	FREQUENCY	PERCENT
0	2	6.1
1	1	3.0
1.5	2	6.1
2	6	18.2
2.5	2	6.1
3	6	18.2
3.5	1	3.0
4	5	15.2
5	3	9.1
6	1	3.0
7	1	3.0
8	2	6.1
11	1	3.0

Frequency Missing = 4

TABLE C-12

GEC
Deflection Reseat After "Check-6" Position

DEFLECTED (mm)	FREQUENCY	PERCENT
0	7	21.9
0.5	1	3.1
1	6	18.8
1.5	4	12.5
2	6	18.8
3	3	9.4
4	2	6.3
6	3	9.4

Frequency Missing = 5

TABLE C-13

GEC
Deflection of Helmet: Subject Looks Up

DEFLECTED (mm)	FREQUENCY	PERCENT
0	3	9.7
1	2	6.5
1.5	1	3.2
2	2	6.5
2.5	1	3.2
3	5	16.1
3.5	1	3.2
4	4	12.9
4.5	1	3.2
5	3	9.7
6	3	9.7
7	3	9.7
8	1	3.2
15	1	3.2

Frequency Missing = 6

TABLE C-14

GEC
Deflection Reseat After Subject Looks Up

DEFLECTED (mm)	FREQUENCY	PERCENT
-3	1	3.3
-1	1	3.3
0	6	20.0
0.5	1	3.3
1	5	16.7
1.5	3	10.0
2	6	20.0
2.5	1	3.3
3	1	3.3
4	2	6.7
4.5	1	3.3
7	1	3.3
11	1	3.3

Frequency Missing = 7

TABLE C-15

GEC
Rotation About X-Axis with Mask

ROTATION*	FREQUENCY	PERCENT
1	24	92.3
3	2	7.7

Frequency Missing = 11

TABLE C-16

GEC
Rotation About Y-Axis with Mask

ROTATION*	FREQUENCY	PERCENT
1	16	61.5
2	7	26.9
3	3	11.5

Frequency Missing = 11

TABLE C-17

GEC
Rotation About Z-Axis with Mask

ROTATION*	FREQUENCY	PERCENT
1	17	65.4
2	6	23.1
3	2	7.7
4	1	3.8

Frequency Missing = 11

* 1 = None
2 = Slight
3 = Moderate
4 = Severe
5 = Excessive

TABLE C-18

GEC
Rotation About X-Axis

ROTATION*	FREQUENCY	PERCENT
1	22	68.8
2	9	28.1
4	1	3.1

Frequency Missing = 5

TABLE C-19

GEC
Rotation About Y-Axis

ROTATION*	FREQUENCY	PERCENT
1	7	21.9
2	6	18.8
3	7	21.9
4	8	25.0
5	4	12.5

Frequency Missing = 5

TABLE C-20

GEC
Rotation About Z-Axis

ROTATION*	FREQUENCY	PERCENT
1	3	9.4
2	9	28.1
3	10	31.3
4	5	15.6
5	5	15.6

Frequency Missing = 5

* 1 = None
2 = Slight
3 = Moderate
4 = Severe
5 = Excessive

TABLE C-21

HON
Forward Deflection of Helmet: 2-lb Force

DEFLECTED (mm)	FREQUENCY	PERCENT
-1	1	3.0
0	3	9.1
1	3	9.1
1.5	2	6.1
2	15	45.5
3	5	15.2
4	3	9.1
5	1	3.0

Frequency Missing = 4

TABLE C-22

HON
Forward Deflection of Helmet: 4-lb Force

DEFLECTED (mm)	FREQUENCY	PERCENT
0	3	9.1
1	1	3.0
2	4	12.1
3	4	12.1
4	9	27.3
5	7	21.2
6	1	3.0
7	2	6.1
9	1	3.0
13	1	3.0

Frequency Missing = 4

TABLE C-23

HON
Forward Deflection Reseat Position with Force Removed

DEFLECTED (mm)	FREQUENCY	PERCENT
-3	1	3.1
0	8	25.0
0.5	1	3.1
1	7	21.9
1.5	3	9.4
2	6	18.8
2.5	1	3.1
3.5	1	3.1
4	3	9.4
7	1	3.1

Frequency Missing = 5

TABLE C-24

HON
Backward Deflection of Helmet: 2-lb Force

DEFLECTED (mm)	FREQUENCY	PERCENT
0	1	3.0
1	1	3.0
2	5	15.2
2.5	2	6.1
3	5	15.2
4	5	15.2
4.5	2	6.1
5	6	18.2
6	2	6.1
7	2	6.1
9	1	3.0
10	1	3.0

Frequency Missing = 4

TABLE C-25

HON

Backward Deflection of Helmet: 4-lb Force

DEFLECTED (mm)	FREQUENCY	PERCENT
2	1	3.2
4	5	16.1
5	1	3.2
6	4	12.9
7	1	3.2
8	5	16.1
9	3	9.7
9.5	1	3.2
10	3	9.7
14	1	3.2
15	1	3.2
16	1	3.2
18	2	6.5
23	1	3.2
75	1	3.2

Frequency Missing = 6

TABLE C-26

HON
Backward Deflection Reseat Position with Force Removed

DEFLECTED (mm)	FREQUENCY	PERCENT
0	1	3.3
0.5	1	3.3
1	4	13.3
1.5	2	6.7
2	4	13.3
2.5	1	3.3
3	3	10.0
4	4	13.3
5	3	10.0
7	2	6.7
9	2	6.7
11	1	3.3
14	1	3.3
18	1	3.3

Frequency Missing = 7

TABLE C-27

HON
Right Deflection of Helmet: 2-lb Force

DEFLECTED (mm)	FREQUENCY	PERCENT
0	1	3.0
1	2	6.1
2	10	30.3
2.5	1	3.0
3	5	15.2
3.5	1	3.0
4	5	15.2
5	4	12.1
6	1	3.0
7	1	3.0
9	2	6.1

Frequency Missing = 4

TABLE C-28

HON
Right Deflection of Helmet: 4-lb Force

DEFLECTED (mm)	FREQUENCY	PERCENT
2	2	6.1
3	3	9.1
4	4	12.1
5	5	15.2
6	4	12.1
7	2	6.1
7.5	1	3.0
8	4	12.1
9	3	9.1
10	1	3.0
11	1	3.0
12	1	3.0
13	1	3.0
17	1	3.0

Frequency Missing = 4

TABLE C-29

HON
Right Deflection Reseat Position with Force Removed

DEFLECTED (mm)	FREQUENCY	PERCENT
0	4	12.1
1	3	9.1
1.5	4	12.1
2	10	30.3
3	4	12.1
3.5	1	3.0
4	5	15.2
6	2	6.1

Frequency Missing = 4

TABLE C-30

HON
Deflection of Helmet: Subject in "Check-6" Position

DEFLECTED (mm)	FREQUENCY	PERCENT
-2	1	3.1
0	5	15.6
0.5	1	3.1
1	5	15.6
2	9	28.1
2.5	2	6.3
3	3	9.4
4	4	12.5
8	1	3.1
15	1	3.1

Frequency Missing = 5

TABLE C-31

HON
Deflection Reseat After "Check-6" Position

DEFLECTED (mm)	FREQUENCY	PERCENT
-2	1	3.1
-1	1	3.1
0	14	43.8
0.5	1	3.1
1	5	15.6
1.5	1	3.1
2	6	18.8
3	3	9.4

Frequency Missing = 5

TABLE C-32

HON
Deflection of Helmet: Subject Looks Up

DEFLECTED (mm)	FREQUENCY	PERCENT
1	4	12.9
2	5	16.1
2.5	1	3.2
3	2	6.5
3.5	1	3.2
4	5	16.1
5	4	12.9
6	5	16.1
7	2	6.5
8	2	6.5

Frequency Missing = 6

TABLE C-33

HON
Deflection Reseat After Subject Looks Up

DEFLECTED (mm)	FREQUENCY	PERCENT
-2	1	3.2
0	9	29.0
0.5	1	3.2
1	3	9.7
2	3	9.7
2.5	3	9.7
3	5	16.1
3.5	3	9.7
4	3	9.7

Frequency Missing = 6

TABLE C-34

HON
Rotation About Z-Axis with Mask

DEFLECTED (mm)	FREQUENCY	PERCENT
2	3	13.0
3	3	13.0

Frequency Missing = 14

TABLE C-35

HON
Rotation About X-Axis with Mask

ROTATION*	FREQUENCY	PERCENT
1	23	100.0

Frequency Missing = 14

TABLE C-36

HON
Rotation About Y-Axis with Mask

ROTATION*	FREQUENCY	PERCENT
1	19	82.6
2	2	8.7
3	2	8.7

Frequency Missing = 14

TABLE C-37

HON
Rotation About Z-Axis with Mask

ROTATION*	FREQUENCY	PERCENT
1	17	73.9
2	3	13.0
3	3	13.0

Frequency Missing = 14

* 1 = None
2 = Slight
3 = Moderate
4 = Severe
5 = Excessive

TABLE C-38

HON
Rotation About X-Axis

ROTATION*	FREQUENCY	PERCENT
1	26	78.8
2	5	15.2
3	2	6.1

Frequency Missing = 4

TABLE C-39

HON
Rotation About Y-Axis

ROTATION*	FREQUENCY	PERCENT
1	11	33.3
2	8	24.2
3	10	30.3
4	4	12.1

Frequency Missing = 4

TABLE C-40

HON
Rotation About Z-Axis

ROTATION*	FREQUENCY	PERCENT
1	13	39.4
2	7	21.2
3	7	21.2
4	6	18.2

Frequency Missing = 4

* 1 = None
2 = Slight
3 = Moderate
4 = Severe
5 = Excessive

TABLE C-41

KAI-NVG
Forward Deflection of Helmet: 2-lb Force

DEFLECTED (mm)	FREQUENCY	PERCENT
-2	1	2.8
0	1	2.8
1	1	2.8
2	11	30.6
2.5	1	2.8
3	6	16.7
3.5	1	2.8
4	4	11.1
4.5	1	2.8
5	1	2.8
6	4	11.1
7	1	2.8
8	2	5.6
9	1	2.8

Frequency Missing = 1

TABLE C-42

KAI-NVG
Forward Deflection of Helmet: 4-lb Force

VALUE	FREQUENCY	PERCENT
3	4	11.1
4	3	8.3
5	3	8.3
5.5	1	2.8
6	4	11.1
8	2	5.6
9	2	5.6
10	1	2.8
11	3	8.3
12	1	2.8
12.5	1	2.8
13	4	11.1
16	1	2.8
18	1	2.8
21	1	2.8
22	1	2.8
25	1	2.8
38	1	2.8
61	1	2.8

Frequency Missing = 1

TABLE C-43

KAI-NVG
Forward Deflection Reseat Position with Force Removed

VALUE	FREQUENCY	PERCENT
0	2	5.6
0.5	1	2.8
1	1	2.8
1.5	1	2.8
2	7	19.4
3	4	11.1
4	3	8.3
4.5	1	2.8
5	2	5.6
6	4	11.1
7	1	2.8
7.5	1	2.8
8	1	2.8
9	2	5.6
11	1	2.8
17	1	2.8
21	1	2.8
27	1	2.8
42	1	2.8

Frequency Missing = 1

TABLE C-44

KAI-NVG
Backward Deflection of Helmet: 2-lb Force

DEFLECTED (mm)	FREQUENCY	PERCENT
0	1	2.8
2	3	8.3
2.5	1	2.8
3	7	19.4
3.5	1	2.8
4	9	25.0
4.5	2	5.6
5	2	5.6
6	4	11.1
7	3	8.3
8	1	2.8
10	1	2.8
12	1	2.8

Frequency Missing = 1

TABLE C-45

KAI-NVG
Backward Deflection of Helmet: 4-lb Force

DEFLECTED (mm)	FREQUENCY	PERCENT
3	1	2.9
4	3	8.6
4.5	1	2.9
5	1	2.9
5.5	1	2.9
6	4	11.4
7	4	11.4
8	3	8.6
9	4	11.4
10	5	14.3
11	1	2.9
11.5	1	2.9
15	1	2.9
16	1	2.9
17	2	5.7
22	1	2.9
25	1	2.9

Frequency Missing = 2

TABLE C-46

KAI-NVG
Backward Deflection Reseat Position with Force Removed

DEFLECTED (mm)	FREQUENCY	PERCENT
1	3	8.8
2	7	20.6
2.5	2	5.9
3	7	20.6
4	1	2.9
4.5	1	2.9
5	2	5.9
6	3	8.8
7	3	8.8
8	1	2.9
11	1	2.9
14	1	2.9
15	1	2.9
21	1	2.9

Frequency Missing = 3

TABLE C-47

KAI-NVG
Right Deflection of Helmet: 2-lb Force

DEFLECTED (mm)	FREQUENCY	PERCENT
0	1	2.8
1	2	5.6
1.5	2	5.6
2	8	22.2
2.5	1	2.8
3	11	30.6
4	4	11.1
5	3	8.3
7	2	5.6
9	2	5.6

Frequency Missing = 1

TABLE C-48

KAI-NVG
Right Deflection of Helmet: 4-lb Force

DEFLECTED (mm)	FREQUENCY	PERCENT
0.5	1	2.8
2	1	2.8
3	2	5.6
3.5	1	2.8
4	2	5.6
5	5	13.9
6	5	13.9
7	6	16.7
8	5	13.9
9	2	5.6
10	3	8.3
11	1	2.8
13	1	2.8
17	1	2.8

Frequency Missing = 1

TABLE C-49

KAI-NVG
Right Deflection Reseat Position with Force Removed

DEFLECTED (mm)	FREQUENCY	PERCENT
0	2	5.6
0.5	3	8.3
1	5	13.9
1.5	6	16.7
2	5	13.9
2.5	3	8.3
3	6	16.7
4	2	5.6
4.5	2	5.6
5	1	2.8
11	1	2.8

Frequency Missing = 1

TABLE C-50

KAI-NVG
Deflection of Helmet: Subject in "Check-6" Position

DEFLECTED (mm)	FREQUENCY	PERCENT
0	2	5.6
0.5	1	2.8
1	5	13.9
1.5	4	11.1
2	9	25.0
2.5	2	5.6
3	6	16.7
4	2	5.6
5	2	5.6
6	2	5.6
7	1	2.8

Frequency Missing = 1

TABLE C-51

KAI-NVG
Deflection Reseat After "Check-6" Position

DEFLECTED (mm)	FREQUENCY	PERCENT
-2	1	2.8
0	13	36.1
0.5	3	8.3
1	11	30.6
1.5	3	8.3
2	2	5.6
2.5	1	2.8
4	2	5.6

Frequency Missing = 1

TABLE C-52

KAI-NVG
Deflection of Helmet: Subject Looks Up

DEFLECTED (mm)	FREQUENCY	PERCENT
0	1	2.9
1.5	1	2.9
2	5	14.3
2.5	2	5.7
3	5	14.3
3.5	2	5.7
4	4	11.4
5	3	8.6
6	4	11.4
7	4	11.4
8	1	2.9
10	1	2.9
11	1	2.9
16	1	2.9

Frequency Missing = 2

TABLE C-53

KAI-NVG
Deflection Reseat After Subject Looks Up

DEFLECTION (mm)	FREQUENCY	PERCENT
-1	1	2.9
0	10	28.6
1	6	17.1
1.5	2	5.7
2	4	11.4
2.5	1	2.9
3	6	17.1
4	2	5.7
5	1	2.9
7	1	2.9
12	1	2.9

Frequency Missing = 2

TABLE C-54

KAI-NVG
Rotation About X-Axis with Mask

ROTATION*	FREQUENCY	PERCENT
1	26	100.0

Frequency Missing = 11

TABLE C-55

KAI-NVG
Rotation About Y-Axis with Mask

ROTATION*	FREQUENCY	PERCENT
1	19	73.1
2	6	23.1
3	1	3.8

Frequency Missing = 11

TABLE C-56

KAI-NVG
Rotation About Z-Axis with Mask

ROTATION*	FREQUENCY	PERCENT
1	23	88.5
2	3	11.5

Frequency Missing = 11

* 1 = None
2 = Slight
3 = Moderate
4 = Severe
5 = Excessive

TABLE C-57

KAI-NVG
Rotation About X-Axis

ROTATION*	FREQUENCY	PERCENT
1	29	82.9
2	1	2.9
3	4	11.4
4	1	2.9

Frequency Missing = 2

TABLE C-58

KAI-NVG
Rotation About Y-Axis

ROTATION*	FREQUENCY	PERCENT
1	7	20.0
2	9	25.7
3	12	34.3
4	5	14.3
5	2	5.7

Frequency Missing = 2

TABLE C-59

KAI-NVG
Rotation About Z-Axis

ROTATION*	FREQUENCY	PERCENT
1	14	40.0
2	8	22.9
3	7	20.0
4	6	17.1

Frequency Missing = 2

* 1 = None
2 = Slight
3 = Moderate
4 = Severe
5 = Excessive

TABLE C-60

KAI-HMD
Forward Deflection of Helmet: 2-lb Force

DEFLECTED (mm)	FREQUENCY	PERCENT
1	2	13.3
1.5	3	20.0
2	2	13.3
4	3	20.0
6	1	6.7
9	1	6.7
11	1	6.7
17	1	6.7
21	1	6.7

Frequency Missing = 22

TABLE C-61

KAI-HMD
Forward Deflection of Helmet: 4-lb Force

DEFLECTION (mm)	FREQUENCY	PERCENT
3	2	13.3
4	1	6.7
4.5	2	13.3
7	2	13.3
7.5	1	6.7
10	1	6.7
11	1	6.7
12	1	6.7
21	1	6.7
28	1	6.7
33	1	6.7
37	1	6.7

Frequency Missing = 22

TABLE C-62

KAI-HMD

Forward Deflection Reseat Position with Force Removed

DEFLECTED (mm)	FREQUENCY	PERCENT
0.5	1	6.7
1.5	2	13.3
2	3	20.0
3	2	13.3
4	1	6.7
6	1	6.7
10	1	6.7
12.5	1	6.7
13	1	6.7
18	1	6.7
30	1	6.7

Frequency Missing = 22

TABLE C-63

KAI-HMD

Backward Deflection of Helmet: 2-lb Force

DEFLECTED (mm)	FREQUENCY	PERCENT
0	2	13.3
1	1	6.7
2	3	20.0
3	1	6.7
4	4	26.7
5	1	6.7
6	1	6.7
7	1	6.7
8	1	6.7

Frequency Missing = 22

TABLE C-64

KAI-HMD
Backward Deflection of Helmet: 4-lb Force

DEFLECTED (mm)	FREQUENCY	PERCENT
0	1	6.7
1	1	6.7
2.5	1	6.7
3	1	6.7
4	1	6.7
5	1	6.7
6	2	13.3
7	2	13.3
8	1	6.7
10	1	6.7
11	2	13.3
16	1	6.7

Frequency Missing = 22

TABLE C-65

KAI-HMD
Backward Deflection Reseat Position with Force Removed

DEFLECTED (mm)	FREQUENCY	PERCENT
0	3	20.0
1	2	13.3
2	1	6.7
2.5	1	6.7
3	2	13.3
3.5	2	13.3
4	1	6.7
6	1	6.7
6.5	1	6.7
14	1	6.7

Frequency Missing = 22

TABLE C-66

KAI-HMD
Right Deflection of Helmet: 2-lb Force

DEFLECTED (mm)	FREQUENCY	PERCENT
1.5	1	6.7
2	4	26.7
3	2	13.3
4	4	26.7
6	3	20.0
7	1	6.7

Frequency Missing = 22

TABLE C-67

KAI-HMD
Right Deflection of Helmet: 4-lb Force

DEFLECTED (mm)	FREQUENCY	PERCENT
3.5	2	13.3
4	1	6.7
5	3	20.0
6	3	20.0
7	2	13.3
8	1	6.7
10	1	6.7
11	2	13.3

Frequency Missing = 22

TABLE C-68

KAI-HMD
Right Deflection Reseat Position with Force Removed

DEFLECTED (mm)	FREQUENCY	PERCENT
0	1	6.7
1	4	26.7
2	1	6.7
2.5	1	6.7
3	4	26.7
4	3	20.0
8	1	6.7

Frequency Missing = 22

TABLE C-69

KAI-HMD
Deflection of Helmet: Subject in "Check-6" Position

DEFLECTED (mm)	FREQUENCY	PERCENT
1	3	20.0
1.5	3	20.0
2	5	33.3
2.5	2	13.3
3	2	13.3

Frequency Missing = 22

TABLE C-70

KAI-HMD
Deflection Reseat After "Check-6" Position

DEFLECTED (mm)	FREQUENCY	PERCENT
-2	1	6.7
0	3	20.0
1	8	53.3
1.5	1	6.7
2	2	13.3

Frequency Missing = 22

TABLE C-71

KAI-HMD
Deflection of Helmet: Subject Looks Up

DEFLECTED (mm)	FREQUENCY	PERCENT
0	1	6.7
1.5	1	6.7
2	1	6.7
3	2	13.3
3.5	2	13.3
4	2	13.3
5	3	20.0
6	2	13.3
11	1	6.7

Frequency Missing = 22

TABLE C-72

KAI-HMD
Deflection Reseat After Subject Looks Up

DEFLECTED (mm)	FREQUENCY	PERCENT
0	4	26.7
1	3	20.0
1.5	1	6.7
2	1	6.7
2.5	1	6.7
3	4	26.7
4.5	1	6.7

Frequency Missing = 22

TABLE C-73

KAI-HMD
Rotation About X-Axis with Mask

ROTATION*	FREQUENCY	PERCENT
1	9	100.0

Frequency Missing = 28

TABLE C-74

KAI-HMD
Rotation About Y-Axis with Mask

ROTATION*	FREQUENCY	PERCENT
1	6	66.7
2	3	33.3

Frequency Missing = 28

TABLE C-75

KAI-HMD
Rotation About Z-Axis with Mask

ROTATION*	FREQUENCY	PERCENT
1	8	88.9
3	1	11.1

Frequency Missing = 28

TABLE C-76

KAI-HMD
Rotation About X-Axis

ROTATION*	FREQUENCY	PERCENT
1	14	100.0

Frequency Missing = 23

* 1 = None
2 = Slight
3 = Moderate
4 = Severe
5 = Excessive

TABLE C-77

KAI-HMD
Rotation About Y-Axis

ROTATION*	FREQUENCY	PERCENT
1	1	7.1
2	4	28.6
3	6	42.9
4	3	21.4

Frequency Missing = 23

TABLE C-78

KAI-HMD
Rotation About Z-Axis

ROTATION*	FREQUENCY	PERCENT
1	2	14.3
2	5	35.7
3	4	28.6
4	2	14.3
5	1	7.1

Frequency Missing = 23

* 1 = None
2 = Slight
3 = Moderate
4 = Severe
5 = Excessive

TABLE C-79

I-NIGHTS COMFORT DATA BY HELMET TYPE

	GEC		HON		KAI-NVG		KAI-HMD	
	Freq	%	Freq	%	Freq	%	Freq	%
HELMET TIGHTNESS								
Excellent	0	0.0	0	0.0	0	0.0	1	6.7
Good	6	16.7	2	6.1	2	5.6	1	6.7
Average	22	61.1	15	45.5	22	61.1	6	40.0
Fair	7	19.4	15	45.5	10	27.8	7	46.7
Poor	1	2.8	1	3.0	2	5.6	0	0.0
Frequency Missing	1		4		1		22	
HELMET COMFORT								
Excellent	17	47.2	11	33.3	13	36.1	3	20.0
Good	11	30.6	16	48.5	15	41.7	5	33.3
Average	4	11.1	5	15.2	3	8.3	4	26.7
Fair	3	8.3	1	3.0	4	11.1	1	6.7
Poor	1	2.8	0	0.0	1	2.8	2	13.3
Frequency Missing	1		4		1		22	
EARCUP TIGHTNESS OR RIGHT EARCUP TIGHTNESS								
Excellent	0	0.0	1	3.1	0	0.0	0	0.0
Good	1	2.8	1	3.1	0	0.0	0	0.0
Average	24	66.7	15	46.9	26	72.2	10	66.7
Fair	9	25.0	11	34.3	9	25.0	5	33 3
Poor	2	5.6	4	12.5	1	2.8	0	0.0
Frequency Missing	1		5		1		22	
LEFT EARCUP TIGHTNESS IF DIFFERENT FROM RIGHT								
Excellent	0	0.0	0	0.0	0	0.0	0	0.0
Good	0	0.0	1	25.0	0	0.0	0	0.0
Average	0	0.0	1	25.0	0	0.0	0	0.0
Fair	4	2	50.0	0	0.0	1	50.0	100.0
Poor	0	0.0	0	0.0	0	0.0	1	50.0
Frequency Missing	36		33		37		35	
EARCUP COMFORT								
Excellent	24	66.7	17	51.5	25	69.4	9	60.0
Good	4	11.1	10	30.3	5	13.9	2	13.3
Average	5	13.9	3	9.1	5	13.9	4	26.7
Fair	3	8.3	3	9.1	1	2.8	0	0.0

	GEC Freq	GEC %	HON Freq	HON %	KAI-NVG Freq	KAI-NVG %	KAI-HMD Freq	KAI-HMD %
Poor	0	0.0	0	0.0	0	0.0	0	0.0
Frequency Missing	1		4		1		22	
COMFORT LEVEL AT HOT SPOTS								
Excellent	0	0.0	0	0.0	0	0.0	0	0.0
Good	3	33.3	4	44.4	5	38.5	2	16.7
Average	2	22.2	3	33.3	4	30.8	7	58.3
Fair	2	22.2	2	22.2	3	23.1	2	16.7
Poor	2	22.2	0	0.0	1	7.7	1	8.3
Frequency Missing	28		4		24		25	
COMFORT RATING AT PRESSURE SPOTS								
Excellent	0	0.0	1	5.0	2	9.1	0	0.0
Good	7	38.9	12	60.0	7	31.8	2	20.0
Average	5	27.8	3	15.0	9	40.9	6	60.0
Fair	3	16.7	4	20.0	3	13.6	1	10.0
Poor	3	16.7	0	0.0	1	4.5	1	10.0
Frequency Missing	19		17		15		27	
NECK STRAIN								
Excellent	0	0.0	0	0.0	0	0.0	0	0.0
Good	7	77.8	4	57.1	3	42.9	2	66.7
Average	2	22.2	1	14.3	4	57.1	0	0.0
Fair	0	0.0	2	28.6	0	0.0	1	33.3
Poor	0	0.0	0	0.0	0	0.0	0	0.0
Frequency Missing	28		30		30		34	

APPENDIX D

TEST SUBJECT COMMENTS

TEST SUBJECT COMMENTS - GEC

Subject Number	Comment
3	Very top heavy in front. The CG too far forward.
5	Helmet is heavy, especially top or forward heavy.
6	Maybe shave some extra foam from the inside. Felt good. Lightweight compared to the others. More balanced than the others.
12	If it were not for the combiner pressing into the browridge, the rest of the helmet felt okay.
14	Feels heavier as time goes on.
18	I rated comfort for the GEC a "2" because everything was better than the other two (Kaiser and Honeywell) but GEC was too heavy to rate a "1" in comfort. Overall rating was a "1" but I want to stress the weight problem.(GEC heavier than Honeywell but still lighter than Kaiser).
19	The ear cups didn't fit correctly (I couldn't get them in the right place.) Also, a lot of pressure above the ears and directly behind the ears at the same level. There was pressure from the combiners on the brow ridge. The helmet was sitting too high and too far back on the head.
20	Feels good overall. The helmet is good.
21	The helmet was loose, especially when the mask is removed. Perhaps the pad (liner) was not thick enough.
23	The face mask seems to want to rotate down the chin more than before and puts pressure on the bridge of the nose. This may be caused by helmet weight distribution.
25	Good helmet. I like the way the nape straps keep everything stable. I like the way everything (including the battery pack) is enclosed.
26	Chin cup is a hindrance to talking and exerts pressure. It is impossible to eat and eating does occur on lo[illegible] missions. Helmet was least stable along Y axis. Movement of the mouth (talking, stretching jaw, eating) causes helmet to migrate forward and misaligns optics.
26	The (helmet) migration is substantial: at least 2 to 3 cm.

Subject Number	Comment
27	(I) couldn't get optics far enough apart.
29	Outstanding helmet.
30	Ear cups too tight and hurt jaw. If you get it (ear cup adjustment) too tight, you cannot loosen it.
31	Ear cups fit well. Even pressure from the ear cups. (I) really like the straps which control the ear cups, but they (straps) should be heavier because you could easily pull them out. Even pressure from the helmet too. I believe the instability due to loose nape strap. Boom mike and chin strap are irritating after an hour. The nape strap needs to be lower and needs to be separate from the ear cups'(strap). Chin strap buckle hard to learn how to snap. I like the chin cup. (Helmet) fits well on top. It feels good and sits properly. The piece in the back at the nape of the neck needs to sit lower. Optics: very small range of movement. A small degree of movement will make vision (through the optics) impossible. When a person walks up to within three feet, the feeling is uncomfortable: I feel queasy or nauseated. The bottom of the optics restricts the FOV: metal bands look like half-moons and make you want to cross your eyes because of close proximity to the eyes.
32	Not better than Kaiser. Comfortable after one hour.
35	Difficult to adjust the straps in back. Once on, no ability to loosen them (straps). Only to tighten them.
38	Feels a little forward on CG (weight not evenly distributed).
41	Feels relatively heavy. Forward CG. (I) would rate (the helmet overall) an excellent but give it only an average rating due to weight (too heavy) and instability. After one hour, it takes effort to hold head up and stationary. In a 2-3 hour period you may experience severe neck and back discomfort.
44	Nice, snug fit. (I) like the ear cup adjustment straps/clamps. (The straps) in back give it a nice fit.
47	Overall, very comfortable but very, very heavy and poor CG.

TEST SUBJECT COMMENTS - HONEYWELL

Subject Number	Comment
4	(I) would not want to wear this for an hour again. (There is) play in the right optics but not the left. This caused overlap in the adjustment of the optics.
6	When helmet was removed, head and ears itched.
10	Chin strap itches.
16	Ear cups hurt ears. I do not believe that it was due to the padding (it was just too tight). The surface of the ear cups is too hard and was the reason for the discomfort. I believe that if I were in a situation where it would be extremely hazardous to remove the helmet, I still could only wear it for one and a half to two hours. I would like to know if the operational Honeywell has ear cups constructed with the same materials.
18	Helmet seems lighter so no neck discomfort. This is less comfortable around the ears. I like Honeywell better than Kaiser even though both were good.
19	This helmet wasn't nearly as tight when I was fit for the liner. (Tightness is around the ears.)
20	The helmet is pushing on my glasses.
22	CG farther forward than GEC. Mask was looser and may have contributed to instability.
23	Weight or heaviness caused neck strain. Right jaw muscle is sore (from) some sort of pressure but not certain where the pressure point was.
25	Helmet feels good. Not impressed with the optics adjustability. The optics need to move closer together to accommodate a smaller IPD.
27	Couldn't get optics far enough apart. Optics are terrible. They were difficult to adjust. The acuity was poor. When I was fine-tuning the acuity, I couldn't see any adjustment occurring.
30	An excellent fit. Hard to put on (narrowness, ear pads, etc.)
31	Upon donning, ear cups need pads: very uncomfortable. Chin strap mounted too high on the helmet. It should be mounted lower. Except for ear cup pain, overall fit and comfort is the best. Centered best.

Subject Number	Comment
	Weight distribution best of all three. Boom mike and chin strap tangle. Knobs used to adjust optics hard to use (hard to grasp). Optics limit the field of view at the bottom where pilots customarily glance below to view controls. There are reflections off the prisms.
35	Center of gravity a bit forward and exerts pressure on the forehead. There is a depth difference between the rim of the ear cup and the ear pad. The ear pad needs to accommodate those with very cartilaginous (fleshy) ears.
41	Nice snug fit for helmet shell but ear cup portion needs to be closer to head (distance between ear cups needs to be lessened).
44	Comfortable except for slight pressure on the forehead.
47	It feels like the helmet wants to rotate forward off his head. The nape strap is as tight as possible. Otherwise, a great fit. Honeywell discomfort: not uncomfortable, but the forward rotation makes you feel the helmet is going to rotate off your head.
50	Better (overall) than Kaiser but not as good as GEC. Can move the ear cups but don't retain the position like in the Kaiser. Get bigger ear cup molds!

TEST SUBJECT COMMENTS - KAISER

Subject Number	Comment
2	Pretty good fit.
3	Slight effort to keep head up. Top heavy and weight too far forward. Helmet comes up pretty far in the back so there is no support. Helmet is top-heav and is too far forward. When you put your head back helmet is comfortabl
4	Feels good!
5	The liner may not be properly made or inserted.
6	Heavy forward. Slightly uncomfortable (feels like pressure on the sinus nerve).
8	Feels like the helmet is rotated too far forward (i.e., too low on the forehead). Otherwise, comfortable.
9	An hour was too long (half an hour would have been enough). 20 minutes into the session, a hot spot developed. It got to a certain painfulness and then did not lessen or increase in pain.
13	(Liner) fitting process was intolerable: too damn hot! Liner did not seem to fit the helmet properly. Chin strap poorly located. (Users) need easier access. There are two rounded protrusions directly above the area of the hot spots in the helmet shell. What the hell are those for?
14	A hot spot developed behind the left ear but was relieved by the time one hour was up.
15	I want to take it off!!! The ear cups didn't adjust well. I needed them to slant at a different angle than what was achievable.
18	Weight causes neck discomfort on the side which extends up into the jaw (on the left side only).
21	(Initially) felt more comfortable than the Honeywell but now (after one hour) there is more pressure (than Honeywell). This is more stable than Honeywell.
22	Overall, the helmet is heavy and it can be felt on the top of the head.
26	Well-balanced.

Subject Number	Comment
27	Optics good on Kaiser. Rated "fair" because very uncomfortable but optics were good.
29	Overall, (I) do not like the fit.
30	Strap for chin strap needs to be longer.
31	Chin strap is too short. Boom mike and chin strap tangle. Ear cups don't stick so they fall off when try to don the helmet. Neck pad is a piece of garbage (GEC design far superior). Helmet is cut way too high in the back - responsible for the extreme movement about Y. Hot spots caused by thin padding between energy liner and personal liner on the sides. The nape strap still needs to be separate: you can choke yourself before you get it tight at the nape. Clarity of optics great and the ability to flip the optics great too. It was possible to keep head up and stationary but constant frontward slippage of the helmet felt uncomfortable. Weight (of the helmet) was too far forward. Chin strap too short on attachment side. Space between liner in front and the helmet itself was about a finger width so it lacked the support to keep the helmet from slipping forward. Adjustments almost useless for the back adjustments (nape straps). Padding under nape strap wads up. Stupid design. Adjustment for strap and boom mike interfere and a second party is necessary to untangle it. The optics are difficult to adjust (flip up and down) depending on the hand that you use. Best optics (best=clearest vision). Worst fit and worst strap system. Least restriction of vision. No operator control of optical adjustments along all axes.
32	Extremely heavy with a tendency to pull the head forward. If you look down, it (helmet) strains the neck. Weight of the helmet is giving (me) a headache.
35	Nape strap sucks. Large liner makes the difference in terms of uneven weight distribution. Still felt pressure on the forehead, but could wear the 5K longer. Still needs better nape adjustment or a weight to counterbalance the back weight. The chin strap tends to twist. Make the snap (fastener) piece (strap) longer. Making liner even longer in the back would help. I like the cushioning in the ear cup. Once the helmet is on, the adjustability is small to none. I like the ear cups of this helmet the best.
38	It hurts. I want to take it off!
41	Balance pretty good. Helmet lightweight. Chin strap awkward to manipulate.
44	Pressure on the temple area is evenly distributed.
47	Best balanced of the three (helmets). CG a bit forward heavy but best anyway.

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